09/914944

Copy for the Elected Office (EO/US)

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

LEGG, Cyrus, James, Grahame
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

Date of mailing (day/month/year) 07 September 2001 (07.09.01)	
Applicant's or agent's file reference CJGLMPC/4802	**IMPORTANT NOTIFICATION**
International application No. PCT/GB00/00768	**International filing date** (day/month/year) 03 March 2000 (03.03.00)

1. The following indications appeared on record concerning:

[X] the applicant [X] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
MEARS, Robert, Joseph 50 Hurst Park Avenue Cambridge CB4 2AE United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
MEARS, Robert, Joseph 50 Hurst Park Avenue Cambridge CB4 2AE United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

The above-named is to be recorded as inventor and applicant for all designated States.

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer R. Raissi
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 15 December 2000 (15.12.00)	
International application No. PCT/GB00/00768	**Applicant's or agent's file reference** CJGLMPC/4802
International filing date (day/month/year) 03 March 2000 (03.03.00)	**Priority date** (day/month/year) 05 March 1999 (05.03.99)
Applicant MEARS, Robert, Joseph et al	

1. The designated Office is hereby notified of its election made:

   [X] in the demand filed with the International Preliminary Examining Authority on:

   19 September 2000 (19.09.00)

   [ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was [ ] was not

   made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer Pascal Piriou Telephone No.: (41-22) 338.83.38

PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No.

International Filing Date

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference *(if desired) (12 characters maximum)* CJGLMPC/4802

Box No. I TITLE OF INVENTION

Improvements in and relating to gratings

Box No. II APPLICANT

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

Fujitsu Telecommunications Europe Ltd.,
Solihull Parkway,
Birmingham Business Park,
Birmingham.
B37 7YU
United Kingdom

☐ This person is also inventor.

Telephone No.

Facsimile No.

Teleprinter No.

State *(that is, country)* of nationality: United Kingdom

State *(that is, country)* of residence: United Kingdom

This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

MEARS, Robert Joseph
50 Hurst Park Avenue,
Cambridge.
CB4 2AE
United Kingdom

This person is:

☐ applicant only

☒ applicant and inventor

☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: United Kingdom

State *(that is, country)* of residence: United Kingdom

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.)*

LEGG, Cyrus James Grahame
Abel & Imray,
20 Red Lion Street,
London
WC1R 4PQ
United Kingdom

Telephone No
0171 242 9984

Facsimile No
0171 242 9989

Teleprinter No

☐ **Address for correspondence:** Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.

Continuation of Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

If none of the following sub-boxes is used, this sheet should not be included in the request.

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

PARKER, Michael Charles
38 Byron Avenue
Colchester
Essex CO3 4HG
United Kingdom

This person is:
- [ ] applicant only
- [x] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: United Kingdom

State *(that is, country)* of residence: United Kingdom

This person is applicant for the purposes of:
- [ ] all designated States
- [ ] all designated States except the United States of America
- [x] the United States of America only
- [ ] the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- [ ] applicant only
- [ ] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- [ ] all designated States
- [ ] all designated States except the United States of America
- [ ] the United States of America only
- [ ] the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- [ ] applicant only
- [ ] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- [ ] all designated States
- [ ] all designated States except the United States of America
- [ ] the United States of America only
- [ ] the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- [ ] applicant only
- [ ] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- [ ] all designated States
- [ ] all designated States except the United States of America
- [ ] the United States of America only
- [ ] the States indicated in the Supplemental Box

- [ ] Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No.V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes: at least one must be marked)*:

Regional Patent

☒ **AP** **ARIPO Patent:** GH Ghana, GM Gambia, KE Kenya, LS Lesotho, MW Malawi, SD Sudan, SL Sierra Leone, SZ Swaziland, TZ United Republic of Tanzania, UG Uganda, ZW Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT

☒ **EA** **Eurasian Patent:** AM Armenia, AZ Azerbaijan, BY Belarus, KG Kyrgyzstan, KZ Kazakhstan, MD Republic of Moldova, RU Russian Federation, TJ Tajikistan, TM Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT

☒ **EP** **European Patent:** AT Austria, BE Belgium, CH and LI Switzerland and Liechtenstein, CY Cyprus, DE Germany, DK Denmark, ES Spain, FI Finland, FR France, GB United Kingdom, GR Greece, IE Ireland, IT Italy, LU Luxembourg, MC Monaco, NL Netherlands, PT Portugal, SE Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT

☒ **OA** **OAPI Patent:** BF Burkina Faso, BJ Benin, CF Central African Republic, CG Congo, CI Côte d'Ivoire, CM Cameroon, GA Gabon, GN Guinea, GW Guinea-Bissau, ML Mali, MR Mauritania, NE Niger, SN Senegal, TD Chad, TG Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* ....

National Patent *(if other kind of protection or treatment desired, specify on dotted line)*:

- ☒ AE United Arab Emirates
- ☒ AL Albania
- ☒ AM Armenia
- ☒ AT Austria
- ☒ AU Australia
- ☒ AZ Azerbaijan
- ☒ BA Bosnia and Herzegovina
- ☒ BB Barbados
- ☒ BG Bulgaria
- ☒ BR Brazil
- ☒ BY Belarus
- ☒ CA Canada
- ☒ CH and LI Switzerland and Liechtenstein
- ☒ CN China
- ☒ CR Costa Rica
- ☒ CU Cuba
- ☒ CZ Czech Republic
- ☒ DE Germany
- ☒ DK Denmark
- ☒ DM Dominica
- ☒ EE Estonia
- ☒ ES Spain
- ☒ FI Finland
- ☒ GB United Kingdom
- ☒ GD Grenada
- ☒ GE Georgia
- ☒ GH Ghana
- ☒ GM Gambia
- ☒ HR Croatia
- ☒ HU Hungary
- ☒ ID Indonesia
- ☒ IL Israel
- ☒ IN India
- ☒ IS Iceland
- ☒ JP Japan
- ☒ KE Kenya
- ☒ KG Kyrgyzstan
- ☒ KP Democratic People's Republic of Korea
- ☒ KR Republic of Korea
- ☒ KZ Kazakhstan
- ☒ LC Saint Lucia
- ☒ LK Sri Lanka
- ☒ LR Liberia
- ☒ LS Lesotho
- ☒ LT Lithuania
- ☒ LU Luxembourg
- ☒ LV Latvia
- ☒ MA Morocco
- ☒ MD Republic of Moldova
- ☒ MG Madagascar
- ☒ MK The former Yugoslav Republic of Macedonia
- ☒ MN Mongolia
- ☒ MW Malawi
- ☒ MX Mexico
- ☒ NO Norway
- ☒ NZ New Zealand
- ☒ PL Poland
- ☒ PT Portugal
- ☒ RO Romania
- ☒ RU Russian Federation
- ☒ SD Sudan
- ☒ SE Sweden
- ☒ SG Singapore
- ☒ SI Slovenia
- ☒ SK Slovakia
- ☒ SL Sierra Leone
- ☒ TJ Tajikistan
- ☒ TM Turkmenistan
- ☒ TR Turkey
- ☒ TT Trinidad and Tobago
- ☒ TZ United Republic of Tanzania
- ☒ UA Ukraine
- ☒ UG Uganda
- ☒ US United States of America
- ☒ UZ Uzbekistan
- ☒ VN Viet Nam
- ☒ YU Yugoslavia
- ☒ ZA South Africa
- ☒ ZW Zimbabwe

Check-boxes reserved for designating States which have become party to the PCT after issuance of this sheet:

- ☐ ....
- ☐ ....

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. *(Confirmation (including fees) must reach the receiving Office within the 15-month time limit.)*

Supplemental Box *If the Supplemental Box is not used, this sheet should not be included in the request.*

1. If, in any of the Boxes, the space is insufficient to furnish all the information: in such case, write "Continuation of Box No. ..." [indicate the number of the Box] and furnish the information in the same manner as required according to the captions of the Box in which the space was insufficient, in particular:

(i) if more than two persons are involved as applicants and/or inventors and no "continuation sheet" is available: in such case, write "Continuation of Box No. III" and indicate for each additional person the same type of information as required in Box No. III. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below;

(ii) if, in Box No. II or in any of the sub-boxes of Box No. III, the indication "the States indicated in the Supplemental Box" is checked: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the applicant(s) involved and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is applicant;

(iii) if, in Box No. II or in any of the sub-boxes of Box No. III, the inventor or the inventor/applicant is not inventor for the purposes of all designated States or for the purposes of the United States of America: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the inventor(s) and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is inventor;

(iv) if, in addition to the agent(s) indicated in Box No. IV, there are further agents: in such case, write "Continuation of Box No. IV" and indicate for each further agent the same type of information as required in Box No. IV;

(v) if, in Box No. V, the name of any State (or OAPI) is accompanied by the indication "patent of addition," or "certificate of addition," or if, in Box No. V, the name of the United States of America is accompanied by an indication "continuation" or "continuation-in-part": in such case, write "Continuation of Box No. V" and the name of each State involved (or OAPI), and after the name of each such State (or OAPI), the number of the parent title or parent application and the date of grant of the parent title or filing of the parent application;

(vi) if, in Box No. VI, there are more than three earlier applications whose priority is claimed: in such case, write "Continuation of Box No. VI" and indicate for each additional earlier application the same type of information as required in Box No. VI;

(vii) if, in Box No. VI, the earlier application is an ARIPO application: in such case, write "Continuation of Box No. VI", specify the number of the item corresponding to that earlier application and indicate at least one country party to the Paris Convention for the Protection of Industrial Property or one Member of the World Trade Organization for which that earlier application was filed.

2. If, with regard to the precautionary designation statement contained in Box No. V, the applicant wishes to exclude any State(s) from the scope of that statement: in such case, write "Designation(s) excluded from precautionary designation statement" and indicate the name or two-letter code of each State so excluded.

3. If the applicant claims, in respect of any designated Office, the benefits of provisions of the national law concerning non-prejudicial disclosures or exceptions to lack of novelty: in such case, write "Statement concerning non-prejudicial disclosures or exceptions to lack of novelty" and furnish that statement below.

Continuation of Box No. IV

DARBY,	David	Thomas
COULSON,	Antony	John
BARRY,	Patrick	James
SENIOR,	Janet	
BARDO,	Julian	Eason
MAIR,	Richard	Douglas
HUMPHREYS,	Ceris	Anne
CARTER,	Caroline	Ann
NETTLETON,	John	Victor
LOWTHER,	Deborah	Jane
ADAMS,	Nicola	
PEARSON,	James	Ginn

of ABEL & IMRAY, 20 Red Lion Street, London, WC1R 4PQ, United Kingdom.

Telephone number:	0171 242 9984
Facsimile number:	0171 242 9989
Telegraphic address:	Patentable London WC1
Telex address:	24621 IMRAY G

Box No. VI PRIORITY CLAIM ☐ Further priority claims are indicated in the Supplemental Box.

Filing date of earlier application *(day/month/year)*	Number of earlier application	Where earlier application is: national application: country	regional application:* regional Office	international application: receiving Office
item (1) 5 March 1999 (5/3/99)	9905196.3	GB		
item (2) 19 May 1999 (19/5/99)	9911952.1	GB		
item (3)				

[x] The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office)* identified above as item(s) 1 & 2

* *Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.*

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used)* :

ISA /

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority)*:

Date *(day/month/year)* Number Country *(or regional Office)*

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following number of sheets:

request	: 5
description (excluding sequence listing part)	:
claims	:
abstract	:
drawings	:
sequence listing part of description	:
Total number of sheets	:

This international application is accompanied by the item(s) marked below:

1. ☐ fee calculation sheet
2. ☐ separate signed power of attorney
3. ☐ copy of general power of attorney; reference number, if any:
4. ☐ statement explaining lack of signature
5. ☐ priority document(s) identified in Box No. VI as item(s):
6. ☐ translation of international application into (language):
7. ☐ separate indications concerning deposited microorganism or other biological material
8. ☐ nucleotide and/or amino acid sequence listing in computer readable form
9. ☐ other *(specify)*:

Figure of the drawings which should accompany the abstract: 5

Language of filing of the international application: English

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

Cyrus James Grahame LEGG

For receiving Office use only

1. Date of actual receipt of the purported international application:
2. Drawings: ☐ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA /
6. ☐ Transmittal of search copy delayed until search fee is paid.

For International Bureau use only

Date of receipt of the record copy by the International Bureau:

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:
LEGG, Cyrus, James, Grahame
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

ABEL & IMRAY
CASE NO. 4802
G.O.
22 SEP 2000
A/C? Y
CPA? Y COPIED

Date of mailing (day/month/year) 14 September 2000 (14.09.00)		
Applicant's or agent's file reference CJGLMPC/4802	**IMPORTANT NOTICE**	
International application No. PCT/GB00/00768	**International filing date** (day/month/year) 03 March 2000 (03.03.00)	**Priority date** (day/month/year) 05 March 1999 (05.03.99)
Applicant FUJITSU TELECOMMUNICATIONS EUROPE LTD. et al		

1. Notice is hereby given that the International Bureau has communicated, as provided in Article 20, the international application to the following designated Offices on the date indicated above as the date of mailing of this Notice:
   AU,KP,KR,US

   In accordance with Rule 47.1(c), third sentence, those Offices will accept the present Notice as conclusive evidence that the communication of the international application has duly taken place on the date of mailing indicated above and no copy of the international application is required to be furnished by the applicant to the designated Office(s).

2. The following designated Offices have waived the requirement for such a communication at this time:
   AE,AL,AM,AP,AT,AZ,BA,BB,BG,BR,BY,CA,CH,CN,CR,CU,CZ,DE,DK,DM,EA,EE,EP,ES,FI,GB,GD,GE,GH,GM,HR,HU,ID,IL,IN,IS,JP,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MN,MW,MX,NO,NZ,OA,PL,PT,RO,RU,SD,SE,SG,SI,SK,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,ZA,ZW
   The communication will be made to those Offices only upon their request. Furthermore, those Offices do not require the applicant to furnish a copy of the international application (Rule 49.1(a-bis)).

3. Enclosed with this Notice is a copy of the international application as published by the International Bureau on 14 September 2000 (14.09.00) under No. WO 00/54080

REMINDER REGARDING CHAPTER II (Article 31(2)(a) and Rule 54.2)

If the applicant wishes to postpone entry into the national phase until 30 months (or later in some Offices) from the priority date, a **demand for international preliminary examination** must be filed with the competent International Preliminary Examining Authority before the expiration of 19 months from the priority date.

It is the applicant's sole responsibility to monitor the 19-month time limit.

Note that only an applicant who is a national or resident of a PCT Contracting State which is bound by Chapter II has the right to file a demand for international preliminary examination.

REMINDER REGARDING ENTRY INTO THE NATIONAL PHASE (Article 22 or 39(1))

If the applicant wishes to proceed with the international application in the **national phase**, he must, within 20 months or 30 months, or later in some Offices, perform the acts referred to therein before each designated or elected Office.

For further important information on the time limits and acts to be performed for entering the national phase, see the Annex to Form PCT/IB/301 (Notification of Receipt of Record Copy) and Volume II of the PCT Applicant's Guide.

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer J. Zahra
Facsimile No. (41-22) 740.14.35	Telephone No. (41-22) 338.83.38

Express Mail Label No. EK052277718US

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference CJGLMPC/4802	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/00768	International filing date *(day/month/year)* 03/03/2000	(Earliest) Priority Date *(day/month/year)* 05/03/1999
Applicant FUJITSU TELECOMMUNICATIONS EUROPE LTD. et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 6 sheets.

☐ It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**
   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.
      ☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).
   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :
      ☐ contained in the international application in written form.
      ☐ filed together with the international application in computer readable form.
      ☐ furnished subsequently to this Authority in written form.
      ☐ furnished subsequently to this Authority in computer readble form.
      ☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      ☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished
2. ☐ **Certain claims were found unsearchable** (See Box I).
3. ☒ **Unity of invention is lacking** (see Box II).
4. With regard to the **title**,
   ☐ the text is approved as submitted by the applicant.
   ☒ the text has been established by this Authority to read as follows:
   APERIODIC LONGITUDINAL GRATINGS AND OPTIMISATION METHOD
5. With regard to the **abstract**,
   ☒ the text is approved as submitted by the applicant.
   ☐ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.
6. The figure of the **drawings** to be published with the abstract is Figure No. 10a
   ☐ as suggested by the applicant.
   ☐ because the applicant failed to suggest a figure.
   ☒ because this figure better characterizes the invention.
   ☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/00768

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-26, 48-52, 99-115

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-26, 48-52,99-115

   Longitudinal grating having an aperiodic structure and computation method

2. Claim : 27

   Filter

3. Claims: 28-31

   Dielectric stack

4. Claims: 32-34

   Optical fibre Bragg grating

5. Claims: 35-47

   Waveguide structure

6. Claims: 53-56

   aperiodically-poled non-linear material

7. Claims: 57,58

   Non linear loop mirror

8. Claims: 59-63

   Mach-Zender interferometer

9. Claims: 64-68

   grating assisted coupler

10. Claims: 68-78

    Laser

11. Claims: 79-81

    Fabry-Perot and Raman Laser including the Fabry-Perot.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

12. Claims: 82-95

    Material with a grating modifying an electronic bandgap structure or a grating having its response modified by an electronic potential.

13. Claims: 96-98

    grating in a non-linear medium.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00768

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B5/18 G02B6/16 G02B27/44 G02F1/35 G02F1/377 G02F1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 32187 A (UL HAQ TANVEER ;WEBB KEVIN J (US); GALLAGHER NEAL C (US); PURDUE R) 23 July 1998 (1998-07-23) page 4, line 1 -page 6, line 3; figures 5,19,23 page 9, line 10-27 page 20, line 22 -page 24, line 22 ---	1-26, 48-51, 99-101, 107-114
X	US 5 388 173 A (GLENN WILLIAM H) 7 February 1995 (1995-02-07) column 2, line 14-41; figure 3E column 2, line 65 -column 3, line 13 column 5, line 5-29 --- -/--	1-26,48, 49,99, 102-104, 107-114

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 July 2000	14.09.00
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Casse, M

3

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 335 176 A (COMP GENERALE ELECTRICITE) 4 October 1989 (1989-10-04) page 1, column 21-24; claim 1; figures 3,8B	1-19,48, 49, 109-114
X	US 5 666 224 A (WOOD C.) 9 September 1997 (1997-09-09) column 3, line 53 -column 4, line 31 column 4, line 60 -column 6, line 25 column 8, line 20 -column 9, line 15	1-19, 99-101, 105, 109-115
X	US 5 867 304 A (GALVANAUSKAS ALMANTAS ET AL) 2 February 1999 (1999-02-02) column 3, line 36-46; figure 4 column 8, line 65 -column 9, line 11	1-5, 19-24, 48,49
X	CHANG C P ET AL: "OPTIMIZATION OF A THIN-FILM MULTILAYER DESIGN BY USE OF THE GENERALIZED SIMULATED-ANNEALING METHOD" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 11, 1 June 1990 (1990-06-01), pages 595-597, XP000134492 ISSN: 0146-9592 whole document	1,99,105
A	DOBROWOLSKI J A: "COMPUTER DESIGN OF OPTICAL COATINGS" THIN SOLID FILMS,CH,ELSEVIER-SEQUOIA S.A. LAUSANNE, vol. 163, no. 1, + INDEX, 1 September 1988 (1988-09-01), pages 97-110, XP000046996 ISSN: 0040-6090	

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00768

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9832187 A	23-07-1998	US 5942956 A	24-08-1999
		AU 7356898 A	07-08-1998
US 5388173 A	07-02-1995	CA 2179042 A,C	29-06-1995
		DE 69411590 D	13-08-1998
		DE 69411590 T	12-11-1998
		EP 0736201 A	09-10-1996
		ES 2119372 T	01-10-1998
		JP 9506981 T	08-07-1997
		WO 9517705 A	29-06-1995
EP 0335176 A	04-10-1989	FR 2629217 A	29-09-1989
		AT 105418 T	15-05-1994
		DE 68915041 D	09-06-1994
		DE 68915041 T	18-08-1994
		ES 2052793 T	16-07-1994
		JP 1274102 A	01-11-1989
		US 5245474 A	14-09-1993
US 5666224 A	09-09-1997	AU 659528 B	18-05-1995
		AU 3263393 A	03-08-1993
		CA 2120624 A	22-07-1993
		DE 69324236 D	06-05-1999
		DE 69324236 T	29-07-1999
		EP 0620924 A	26-10-1994
		WO 9314424 A	22-07-1993
		JP 7502837 T	23-03-1995
US 5867304 A	02-02-1999	JP 10333197 A	18-12-1998

PATENT COOPERATION TREATY

REC'D 11 MAY 2001
WIPO PCT

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

14

Applicant's or agent's file reference CJGLMPC/4802	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/00768	International filing date *(day/month/year)* 03/03/2000	Priority date *(day/month/year)* 05/03/1999
International Patent Classification (IPC) or national classification and IPC G02B5/18		
Applicant FUJITSU TELECOMMUNICATIONS EUROPE LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
19/09/2000	09.05.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Casse, M Telephone No. +49 89 2399 2769

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00768

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17)):*
Description, pages:

1-44 as originally filed

Claims, No.:

1-115 as originally filed

Drawings, sheets:

1/30-30/30 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 27-47,53-98.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☐ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☒ no international search report has been established for the said claims Nos. 27-47,53-98.

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

   Novelty (N) Yes: Claims 2-26,48-52,99-115

	No:	Claims	1
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-26,48-52,99-115
Industrial applicability (IA)	Yes:	Claims	1-26,48-52,99-115
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Re Item V

1.) Reference is made to the following documents:

D1 = WO9832187
D2 = US5388173
D3 = EP-A-335176
D4 = US5666224
D5 = US5867304

2.a) The document D1 is regarded as one of the closest prior art to the subject-matter of claim 1, and insofar as this claim can be understood (see Section VIII), this document shows the following features thereof (the references in parentheses applying to this document) a fully arbitrary and aperiodic longitudinal grating for optical or microwave frequencies which is designed by global optimization in order to attain a given response function (p.4 l. 1 to p. 6 l. 3)

D1 appears therefore to destroy the novelty of claim 1.

b) Document D2 discloses Bragg grating with an aperiodic arbitrary profile (see figure 3E) which are designed through Fourier Synthesis. The grating provides thus a desired response characteristic which is related to the Fourier transform of the grating profile (col. 5 l.15-29).

c) D3 gives another example of an arbitrary grating profile having a fractal organisation (see claim 1) in order to provide bandpass, multiple notch or arbitrary comb filters (page 1, l.21-24)

d) D4 describes another design method for aperiodic gratings in order to obtain a given response profile (col. 3, l.53 to col. 4 l. 31, col. 4 line 60 to col. 5 line 31) with a grating made of concatenated sub elements which are optimized by an annealing algorithm.

e) D5 discloses also aperiodic gratings which provide any phase response profile (see figure 4 and col. 3 l. 36-46, col. 8 l. 65 to col. 9 l. 21).

3.) Since global optimisation of aperiodic gratings in order to provide any desired response profile is already largely disclosed by the above-mentioned documents, none of the other independent or dependent claims appear to contain any features which, in combination with the features of any claim to which they refer, would meet the requirements of the PCT in respect of novelty or inventive step.

Re Item VII

1.) Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1 and D2 is not mentioned in the description, nor are these documents identified therein.

2.) The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT.

3.) The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Re Item VIII

1.) The wording "characteristic length associated with the selected response characteristic" and the relative term "significantly" used in claim 1 have no well-recognised technical meaning and leaves the reader in doubt as to the meaning of the technical features to which they refer.

Furthermore, the "characteristic length" is nowhere defined in the description. The only definition given in the application for this term is a cut off wavelength as defined in claim 6. Notwithstanding the fact that this feature is not supported either by the description, this definition is not applicable to the vast majority of embodiments and dependent claims which refer to claim 1.

The application therefore also contravenes Article 5 and 6 PCT.
The subject-matter of claim 1 is therefore interpreted, in view of claim 6 and the phrase bridging page 1 and 2 of the description, as an aperiodic grating having a given response characteristic and in that any repeated unit cell within the grating

is longer than the design wavelength or an arbitrary aperiodic grating without any repeated structure inside.

2.) Although claims 1, 107, 108, 109 and 110 have been drafted as separate in dependent claims, they appear to relate effectively to the same subject-matter and to differ from each other only with regard to the definition of the subject-matter for which protection is sought and in respect of the terminology used for the features of that subject-matter. The aforementioned claims therefore lack conciseness. Moreover, lack of clarity of the claims as a whole arises, since the plurality of independent claims makes it difficult, if not impossible, to determine the matter for which protection is sought, and places an undue burden on others seeking to establish the extent of the protection.

Hence, claims 1, 107, 108, 109 and 110 do not meet the requirements of Article 6 PCT. In particular, claims 108 and 100 appear obscure with regard to the scope of protection sought.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
CJGLMPC/4802		
International application No. PCT/GB00/00768	International filing date (*day/month/year*) 03/03/2000	Priority date (*day/month/year*) 05/03/1999
International Patent Classification (IPC) or national classification and IPC G02B5/18		
Applicant FUJITSU TELECOMMUNICATIONS EUROPE LTD. et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 7 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
19/09/2000	09.05.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Casse, M Telephone No. +49 89 2399 2769

Form PCT/IPEA/409 (cover sheet) (January 1994)

Express Mail Label No. EK052277718US

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
   Description, pages:

   1-44 as originally filed

   Claims, No.:

   1-115 as originally filed

   Drawings, sheets:

   1/30-30/30 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 27-47,53-98.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☐ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. are so unclear that no meaningful opinion could be formed (*specify*):

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☒ no international search report has been established for the said claims Nos. 27-47,53-98.

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

   Novelty (N) Yes: Claims 2-26,48-52,99-115

	No:	Claims	1
Inventive step (IS)	Yes:	Claims	
	No:	Claims	1-26,48-52,99-115
Industrial applicability (IA)	Yes:	Claims	1-26,48-52,99-115
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

3.) Since global optimisation of aperiodic gratings in order to provide any desired response profile is already largely disclosed by the above-mentioned documents, none of the other independent or dependent claims appear to contain any features which, in combination with the features of any claim to which they refer, would meet the requirements of the PCT in respect of novelty or inventive step.

Re Item VII

1.) Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1 and D2 is not mentioned in the description, nor are these documents identified therein.

2.) The independent claims are not in the two-part form in accordance with Rule 6.3(b) PCT.

3.) The features of the claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).

Re Item VIII

1.) The wording "characteristic length associated with the selected response characteristic" and the relative term "significantly" used in claim 1 have no well-recognised technical meaning and leaves the reader in doubt as to the meaning of the technical features to which they refer.

Furthermore, the "characteristic length" is nowhere defined in the description. The only definition given in the application for this term is a cut off wavelength as defined in claim 6. Notwithstanding the fact that this feature is not supported either by the description, this definition is not applicable to the vast majority of embodiments and dependent claims which refer to claim 1.

The application therefore also contravenes Article 5 and 6 PCT.
The subject-matter of claim 1 is therefore interpreted, in view of claim 6 and the phrase bridging page 1 and 2 of the description, as an aperiodic grating having a given response characteristic and in that any repeated unit cell within the grating

Re Item V

1.) Reference is made to the following documents:

D1 = WO9832187
D2 = US5388173
D3 = EP-A-335176
D4 = US5666224
D5 = US5867304

2.a) The document D1 is regarded as one of the closest prior art to the subject-matter of claim 1, and insofar as this claim can be understood (see Section VIII), this document shows the following features thereof (the references in parentheses applying to this document) a fully arbitrary and aperiodic longitudinal grating for optical or microwave frequencies which is designed by global optimization in order to attain a given response function (p.4 l. 1 to p. 6 l. 3)

D1 appears therefore to destroy the novelty of claim 1.

b) Document D2 discloses Bragg grating with an aperiodic arbitrary profile (see figure 3E) which are designed through Fourier Synthesis. The grating provides thus a desired response characteristic which is related to the Fourier transform of the grating profile (col. 5 l.15-29).

c) D3 gives another example of an arbitrary grating profile having a fractal organisation (see claim 1) in order to provide bandpass, multiple notch or arbitrary comb filters (page 1, l.21-24)

d) D4 describes another design method for aperiodic gratings in order to obtain a given response profile (col. 3, l.53 to col. 4 l. 31, col. 4 line 60 to col. 5 line 31) with a grating made of concatenated sub elements which are optimized by an annealing algorithm.

e) D5 discloses also aperiodic gratings which provide any phase response profile (see figure 4 and col. 3 l. 36-46, col. 8 l. 65 to col. 9 l. 21).

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 September 2000 (14.09.2000)

PCT

(10) International Publication Number
WO 00/54080 A3

(51) International Patent Classification[7]: G02B 5/18, 6/16, 27/44, G02F 1/35, 1/377, 1/383

(21) International Application Number: PCT/GB00/00768

(22) International Filing Date: 3 March 2000 (03.03.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9905196.3 5 March 1999 (05.03.1999) GB
9911952.1 21 May 1999 (21.05.1999) GB

(71) Applicant *(for all designated States except US)*: FUJITSU TELECOMMUNICATIONS EUROPE LTD. [GB/GB]; Solihull Parkway, Birmingham Business Park, Birmingham B37 7YU (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: MEARS, Robert, Joseph [GB/GB]; 50 Hurst Park Avenue, Cambridge CB4 2AE (GB). PARKER, Michael, Charles [GB/GB]; 38 Byron Avenue, Colchester, Essex CO3 4HG (GB).

(74) Agents: LEGG, Cyrus, James, Grahame et al.; Abel & Imray, 20 Red Lion Street, London WC1R 4PQ (GB).

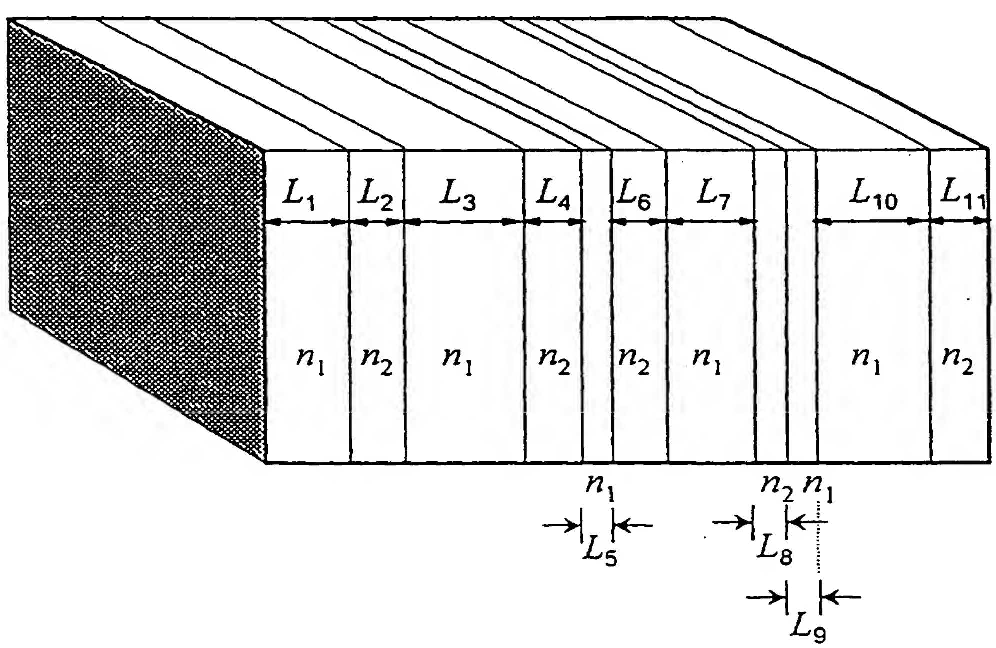
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

[Continued on next page]

(54) Title: APERIODIC LONGITUDINAL GRATINGS AND OPTIMISATION METHOD



(57) Abstract: The invention relates to the field of grating structures. The invention provides a longitudinal grating having an aperiodic structure, wherein the grating has a selected response characteristic and any repeated unit cell in the structure is significantly longer than a characteristic length associated with the selected response characteristic.

WO 00/54080 A3

Express Mail Label No. EK052277718US

(88) Date of publication of the international search rep... :
14 December ...0

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00768

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B5/18 G02B6/16 G02B27/44 G02F1/35 G02F1/377
G02F1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 32187 A (UL HAQ TANVEER ;WEBB KEVIN J (US); GALLAGHER NEAL C (US); PURDUE R) 23 July 1998 (1998-07-23) page 4, line 1 -page 6, line 3; figures 5,19,23 page 9, line 10-27 page 20, line 22 -page 24, line 22 ---	1-26, 48-51, 99-101, 107-114
X	US 5 388 173 A (GLENN WILLIAM H) 7 February 1995 (1995-02-07) column 2, line 14-41; figure 3E column 2, line 65 -column 3, line 13 column 5, line 5-29 ---	1-26,48, 49,99, 102-104, 107-114

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 July 2000	14.09.00

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Casse, M

3

Form PCT/ISA/210 (second sheet) (July 1992)

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 335 176 A (COMP GENERALE ELECTRICITE) 4 October 1989 (1989-10-04) page 1, column 21-24; claim 1; figures 3,8B	1-19,48, 49, 109-114
X	US 5 666 224 A (WOOD C.) 9 September 1997 (1997-09-09) column 3, line 53 -column 4, line 31 column 4, line 60 -column 6, line 25 column 8, line 20 -column 9, line 15	1-19, 99-101, 105, 109-115
X	US 5 867 304 A (GALVANAUSKAS ALMANTAS ET AL) 2 February 1999 (1999-02-02) column 3, line 36-46; figure 4 column 8, line 65 -column 9, line 11	1-5, 19-24, 48,49
X	CHANG C P ET AL: "OPTIMIZATION OF A THIN-FILM MULTILAYER DESIGN BY USE OF THE GENERALIZED SIMULATED-ANNEALING METHOD" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 11, 1 June 1990 (1990-06-01), pages 595-597, XP000134492 ISSN: 0146-9592 whole document	1,99,105
A	DOBROWOLSKI J A: "COMPUTER DESIGN OF OPTICAL COATINGS" THIN SOLID FILMS,CH,ELSEVIER-SEQUOIA S.A. LAUSANNE, vol. 163, no. 1, + INDEX, 1 September 1988 (1988-09-01), pages 97-110, XP000046996 ISSN: 0040-6090	

3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/00768

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-26, 48-52, 99-115

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-26, 48-52,99-115

   Longitudinal grating having an aperiodic structure and computation method

2. Claim : 27

   Filter

3. Claims: 28-31

   Dielectric stack

4. Claims: 32-34

   Optical fibre Bragg grating

5. Claims: 35-47

   Waveguide structure

6. Claims: 53-56

   aperiodically-poled non-linear material

7. Claims: 57,58

   Non linear loop mirror

8. Claims: 59-63

   Mach-Zender interferometer

9. Claims: 64-68

   grating assisted coupler

10. Claims: 68-78

    Laser

11. Claims: 79-81

    Fabry-Perot and Raman Laser including the Fabry-Perot.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

12. Claims: 82-95

Material with a grating modifying an electronic bandgap structure or a grating having its response modified by an electronic potential.

13. Claims: 96-98

grating in a non-linear medium.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00768

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9832187 A	23-07-1998	US 5942956 A	24-08-1999
		AU 7356898 A	07-08-1998
US 5388173 A	07-02-1995	CA 2179042 A,C	29-06-1995
		DE 69411590 D	13-08-1998
		DE 69411590 T	12-11-1998
		EP 0736201 A	09-10-1996
		ES 2119372 T	01-10-1998
		JP 9506981 T	08-07-1997
		WO 9517705 A	29-06-1995
EP 0335176 A	04-10-1989	FR 2629217 A	29-09-1989
		AT 105418 T	15-05-1994
		DE 68915041 D	09-06-1994
		DE 68915041 T	18-08-1994
		ES 2052793 T	16-07-1994
		JP 1274102 A	01-11-1989
		US 5245474 A	14-09-1993
US 5666224 A	09-09-1997	AU 659528 B	18-05-1995
		AU 3263393 A	03-08-1993
		CA 2120624 A	22-07-1993
		DE 69324236 D	06-05-1999
		DE 69324236 T	29-07-1999
		EP 0620924 A	26-10-1994
		WO 9314424 A	22-07-1993
		JP 7502837 T	23-03-1995
US 5867304 A	02-02-1999	JP 10333197 A	18-12-1998

is longer than the design wavelength or an arbitrary aperiodic grating without any repeated structure inside.

2.) Although claims 1, 107, 108, 109 and 110 have been drafted as separate in dependent claims, they appear to relate effectively to the same subject-matter and to differ from each other only with regard to the definition of the subject-matter for which protection is sought and in respect of the terminology used for the features of that subject-matter. The aforementioned claims therefore lack conciseness. Moreover, lack of clarity of the claims as a whole arises, since the plurality of independent claims makes it difficult, if not impossible, to determine the matter for which protection is sought, and places an undue burden on others seeking to establish the extent of the protection.

Hence, claims 1, 107, 108, 109 and 110 do not meet the requirements of Article 6 PCT. In particular, claims 108 and 100 appear obscure with regard to the scope of protection sought.

PATENT COOPERATION TREATY

ABEL ...
CASE No. ...
CO
27 DEC 2000
A/C?
CPA?

From the INTERNATIONAL BUREAU

PCT

INFORMATION CONCERNING ELECTED OFFICES NOTIFIED OF THEIR ELECTION

(PCT Rule 61.3)

To:

LEGG, Cyrus, James, Grahame
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

Date of mailing (day/month/year) 15 December 2000 (15.12.00)	
Applicant's or agent's file reference CJGLMPC/4802	**IMPORTANT INFORMATION**

International application No.	International filing date (day/month/year)	Priority date (day/month/year)
PCT/GB00/00768	03 March 2000 (03.03.00)	05 March 1999 (05.03.99)

Applicant
FUJITSU TELECOMMUNICATIONS EUROPE LTD. et al

1. The applicant is hereby informed that the International Bureau has, according to Article 31(7), notified each of the following Offices of its election:

   AP :GH,GM,KE,LS,MW,SD,SL,SZ,TZ,UG,ZW
   EP :AT,BE,CH,CY,DE,DK,ES,FI,FR,GB,GR,IE,IT,LU,MC,NL,PT,SE
   National :AU,BG,CA,CN,CZ,DE,IL,JP,KP,KR,MN,NO,NZ,PL,RO,RU,SE,SK,US

2. The following Offices have waived the requirement for the notification of their election; the notification will be sent to them by the International Bureau only upon their request:

   EA :AM,AZ,BY,KG,KZ,MD,RU,TJ,TM
   OA :BF,BJ,CF,CG,CI,CM,GA,GN,GW,ML,MR,NE,SN,TD,TG
   National :AE,AL,AM,AT,AZ,BA,BB,BR,BY,CH,CR,CU,DK,DM,EE,ES,FI,GB,GD,GE,GH, GM,HR,HU,ID,IN,IS,KE,KG,KZ,LC,LK,LR,LS,LT,LU,LV,MA,MD,MG,MK,MW,MX,PT,SD, SG,SI,SL,TJ,TM,TR,TT,TZ,UA,UG,UZ,VN,YU,ZA,ZW

3. The applicant is reminded that he must enter the "national phase" **before the expiration of 30 months from the priority date** before each of the Offices listed above. This must be done by paying the national fee(s) and furnishing , if prescribed, a translation of the international application (Article 39(1)(a)), as well as, where applicable, by furnishing a translation of any annexes of the international preliminary examination report (Article 36(3)(b) and Rule 74.1).

   Some offices have fixed time limits expiring later than the above-mentioned time limit. For detailed information about the applicable time limits and the acts to be performed upon entry into the national phase before a particular Office, see Volume II of the PCT Applicant's Guide.

   The entry into the European regional phase is postponed **until 31 months from the priority date** for all States designated for the purposes of obtaining a European patent.

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No. (41-22) 740.14.35	Authorized officer: Pascal Piriou Telephone No. (41-22) 338.83.38

NM

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 September 2000 (14.09.2000)

PCT

(10) International Publication Number
WO 00/54080 A3

(51) International Patent Classification⁷: G02B 5/18, 6/16, 27/44, G02F 1/35, 1/377, 1/383

(21) International Application Number: PCT/GB00/00768

(22) International Filing Date: 3 March 2000 (03.03.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
9905196.3 5 March 1999 (05.03.1999) GB
9911952.1 21 May 1999 (21.05.1999) GB

(71) Applicant *(for all designated States except US)*: **FUJITSU TELECOMMUNICATIONS EUROPE LTD.** [GB/GB]; Solihull Parkway, Birmingham Business Park, Birmingham B37 7YU (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **MEARS, Robert, Joseph** [GB/GB]; 50 Hurst Park Avenue, Cambridge CB4 2AE (GB). **PARKER, Michael, Charles** [GB/GB]; 38 Byron Avenue, Colchester, Essex CO3 4HG (GB).

(74) Agents: LEGG, Cyrus, James, Grahame et al.; Abel & Imray, 20 Red Lion Street, London WC1R 4PQ (GB).

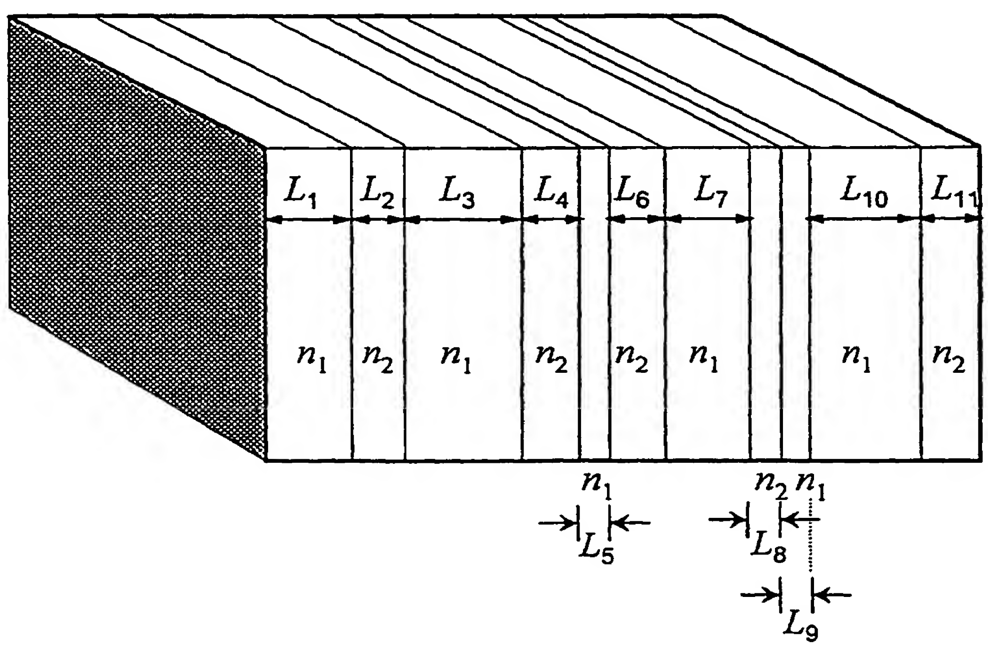
(81) Designated States *(national)*: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

[Continued on next page]

(54) Title: APERIODIC LONGITUDINAL GRATINGS AND OPTIMISATION METHOD



(57) Abstract: The invention relates to the field of grating structures. The invention provides a longitudinal grating having an aperiodic structure, wherein the grating has a selected response characteristic and any repeated unit cell in the structure is significantly longer than a characteristic length associated with the selected response characteristic.

WO 00/54080 A3

(88) Date of publication of the international search report: 14 December 2000

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00768

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B5/18 G02B6/16 G02B27/44 G02F1/35 G02F1/377
G02F1/383

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 32187 A (UL HAQ TANVEER ;WEBB KEVIN J (US); GALLAGHER NEAL C (US); PURDUE R) 23 July 1998 (1998-07-23) page 4, line 1 -page 6, line 3; figures 5,19,23 page 9, line 10-27 page 20, line 22 -page 24, line 22 ---	1-26, 48-51, 99-101, 107-114
X	US 5 388 173 A (GLENN WILLIAM H) 7 February 1995 (1995-02-07) column 2, line 14-41; figure 3E column 2, line 65 -column 3, line 13 column 5, line 5-29 ---	1-26,48, 49,99, 102-104, 107-114

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 July 2000	14.09.00

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Casse, M

3

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 335 176 A (COMP GENERALE ELECTRICITE) 4 October 1989 (1989-10-04) page 1, column 21-24; claim 1; figures 3,8B ---	1-19,48, 49, 109-114
X	US 5 666 224 A (WOOD C.) 9 September 1997 (1997-09-09) column 3, line 53 -column 4, line 31 column 4, line 60 -column 6, line 25 column 8, line 20 -column 9, line 15 ---	1-19, 99-101, 105, 109-115
X	US 5 867 304 A (GALVANAUSKAS ALMANTAS ET AL) 2 February 1999 (1999-02-02) column 3, line 36-46; figure 4 column 8, line 65 -column 9, line 11 ---	1-5, 19-24, 48,49
X	CHANG C P ET AL: "OPTIMIZATION OF A THIN-FILM MULTILAYER DESIGN BY USE OF THE GENERALIZED SIMULATED-ANNEALING METHOD" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 15, no. 11, 1 June 1990 (1990-06-01), pages 595-597, XP000134492 ISSN: 0146-9592 whole document ---	1,99,105
A	DOBROWOLSKI J A: "COMPUTER DESIGN OF OPTICAL COATINGS" THIN SOLID FILMS,CH,ELSEVIER-SEQUOIA S.A. LAUSANNE, vol. 163, no. 1, + INDEX, 1 September 1988 (1988-09-01), pages 97-110, XP000046996 ISSN: 0040-6090 -----	

3

International application No.
PCT/GB 00/00768

INTERNATIONAL SEARCH REPORT

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

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4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-26, 48-52, 99-115

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

1. Claims: 1-26, 48-52,99-115

   Longitudinal grating having an aperiodic structure and computation method

2. Claim : 27

   Filter

3. Claims: 28-31

   Dielectric stack

4. Claims: 32-34

   Optical fibre Bragg grating

5. Claims: 35-47

   Waveguide structure

6. Claims: 53-56

   aperiodically-poled non-linear material

7. Claims: 57,58

   Non linear loop mirror

8. Claims: 59-63

   Mach-Zender interferometer

9. Claims: 64-68

   grating assisted coupler

10. Claims: 68-78

    Laser

11. Claims: 79-81

    Fabry-Perot and Raman Laser including the Fabry-Perot.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

12. Claims: 82-95

    Material with a grating modifying an electronic bandgap structure or a grating having its response modified by an electronic potential.

13. Claims: 96-98

    grating in a non-linear medium.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/00768

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9832187 A	23-07-1998	US 5942956 A	24-08-1999
		AU 7356898 A	07-08-1998
US 5388173 A	07-02-1995	CA 2179042 A,C	29-06-1995
		DE 69411590 D	13-08-1998
		DE 69411590 T	12-11-1998
		EP 0736201 A	09-10-1996
		ES 2119372 T	01-10-1998
		JP 9506981 T	08-07-1997
		WO 9517705 A	29-06-1995
EP 0335176 A	04-10-1989	FR 2629217 A	29-09-1989
		AT 105418 T	15-05-1994
		DE 68915041 D	09-06-1994
		DE 68915041 T	18-08-1994
		ES 2052793 T	16-07-1994
		JP 1274102 A	01-11-1989
		US 5245474 A	14-09-1993
US 5666224 A	09-09-1997	AU 659528 B	18-05-1995
		AU 3263393 A	03-08-1993
		CA 2120624 A	22-07-1993
		DE 69324236 D	06-05-1999
		DE 69324236 T	29-07-1999
		EP 0620924 A	26-10-1994
		WO 9314424 A	22-07-1993
		JP 7502837 T	23-03-1995
US 5867304 A	02-02-1999	JP 10333197 A	18-12-1998

PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 : G02B 5/18, 6/16, 27/44, G02F 1/35, 1/377, 1/383	A2	(11) International Publication Number: WO 00/54080 (43) International Publication Date: 14 September 2000 (14.09.00)

(21) International Application Number: PCT/GB00/00768

(22) International Filing Date: 3 March 2000 (03.03.00)

(30) Priority Data:

9905196.3	5 March 1999 (05.03.99)	GB
9911952.1	21 May 1999 (21.05.99)	GB

(71) Applicant (*for all designated States except US*): FUJITSU TELECOMMUNICATIONS EUROPE LTD. [GB/GB]; Solihull Parkway, Birmingham Business Park, Birmingham B37 7YU (GB).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): MEARS, Robert, Joseph [GB/GB]; 50 Hurst Park Avenue, Cambridge CB4 2AE (GB). PARKER, Michael, Charles [GB/GB]; 38 Byron Avenue, Colchester, Essex CO3 4HG (GB).

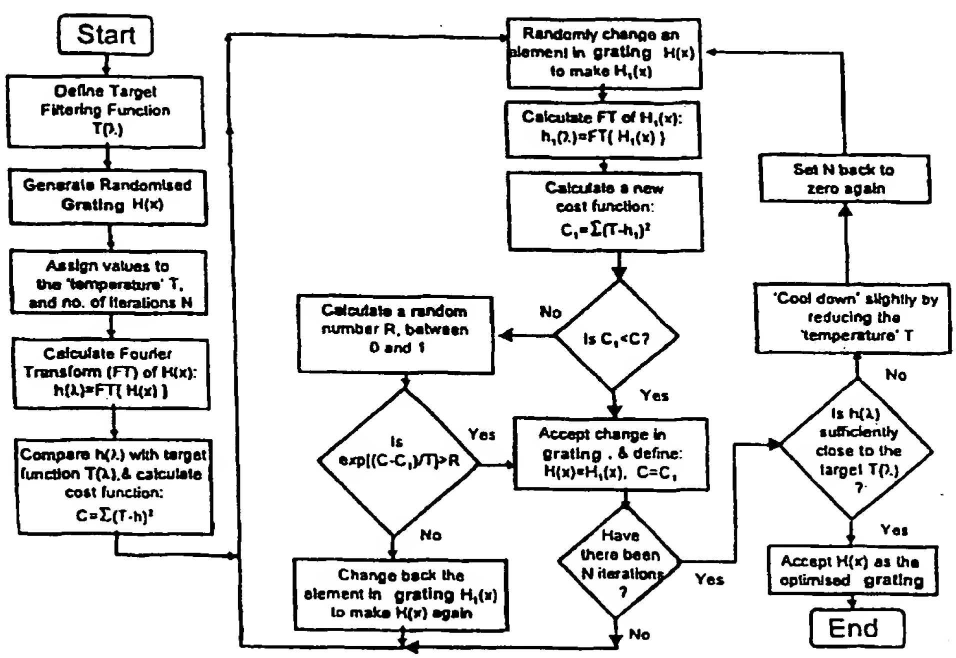
(74) Agents: LEGG, Cyrus, James, Grahame et al.; Abel & Imray, 20 Red Lion Street, London WC1R 4PQ (GB).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published

Without international search report and to be republished upon receipt of that report.

(54) Title: IMPROVEMENTS IN AND RELATING TO GRATINGS



(57) Abstract

The invention relates to the field of grating structures. The invention provides a longitudinal grating having an aperiodic structure, wherein the grating has a selected response characteristic and any repeated unit cell in the structure is significantly longer than a characteristic length associated with the selected response characteristic.

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AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

Improvements in and relating to gratings

This Application relates to the field of grating structures. There has been much interest in both regular and chirped grating structures to define and/or modify the response characteristics of optical and other devices which utilise the properties of wave-like phenomena such as electromagnetic (EM) waves. Examples of devices utilising such structures include Fibre Bragg Gratings (FBGs) and apodised FBGs, in which a slowly-varying chirp is superposed on the grating. Periodic grating structures have been the focus of much attention in a very wide range of applications; for example, in photonic crystals, wherein the band structure may be defined by analogy with the well-known (Bloch) periodic lattice analysis of solid-state physics.

Existing devices are based upon grating structures which are regular in some sense or other. Although various groups have already claimed the use of "aperiodic" gratings or structures in their work, those structures are slowly varying aperiodic structures. A hologram would be an example of a fast-varying structure but is transverse. In this application, "slowly varying" when used in relation to grating structures means that the variation in the structure of the grating has a period significantly longer than the

wavelength being filtered. That distinction is explained further below.

In accordance with the invention there is provided a logitudinal grating as defined in claim 1 and a method of making the same as defined in claim 99.

If all possible aperiodic gratings were to be considered then the vast majority of possible gratings will not have a useful response characteristic and, for gratings with more than a few elements, the skilled person has no way to find a aperiodic grating having a response characteristic that he or she has selected as being useful. Indeed, we believe that it is unlikely that he would expect aperiodic gratings in general to have any useful response characteristic at all.

Although aperiodic structures do not, in general, exhibit a useful band structure, by means of a simple approximate analysis we have found aperiodic structures that exhibit a controllable and useful band structure. At the heart of this analysis is the understanding that it is not the regular periodicity of the real space lattice, but rather the existence of well-defined spatial frequencies (e.g. as revealed by the Fourier Transform (FT) of such an aperiodic structure), which distinguishes a useful aperiodic structure from the vast majority of non-useful (random) aperiodic structures. Thus, we have realised that the Fourier Transform

of an aperiodic grating structure is closely related to its spectral response.

It should be noted that the relevant transform may not be the exact Fourier Transform

$$g(\underline{k}) = F.T.[f(\underline{x})] = \frac{1}{2\pi}\int_{-\infty}^{+\infty} f(\underline{x})e^{-i\underline{k}\cdot\underline{x}}dx$$

but may be a scaled version thereof. The transform will belong to the same class of transforms as a Fourier Transform, but may include scaling factors such as a constant multiplier before the integral or in the exponential component. References to Fourier Transforms to embrace such scaled Transforms and also Fast Fourier Transform equivalents.

We believe that the invention will have widespread applications. In general, material response characteristics result from properties of the atoms making up the material. The characteristics may result directly from the properties of the electrons surrounding the atoms or from the atoms' nuclei or from the arrangement of the atoms relative to each other. It can be seen that the invention makes possible the selection of properties of a material by the introduction of a suitable variation in the atoms making up the material. For example, in an embodiment discussed below, the variation is in refractive index, which can be related to the response of an atom's electrons to an incident EM field.

We have chosen to call an aperiodic structure according to the invention (when applied to photonic structures) an Aperiodic Photonic Band-Gap (APBG) structure. The term A-Periodic Bragg Grating could also be applied to the structures and has the same acronym.

Our APBG structures can be classed as fast-varying structures, which differentiates them from slowly-varying aperiodic structures such as a simple chirped-grating. They are also longitudinal aperiodic structures, which differentiates them from holograms employed in transverse situations.

In the following mathematical discussions, we make a distinction between the underlying grating structure and an overall slowly-varying windowing function, which might be applied so as to apodise the overall response. A windowing function applied to a uniform, periodic grating will tend to yield an overall structure that is aperiodic within the strictest meaning of the term. However, it is the aperiodicity of the underlying grating structure, as discussed below which is of concern here.

An APBG grating (defined below as H) is a structure which cannot be expressed as a simple transformation of a regular grating. In particular the present invention does not include any of the following gating structures:

(1) Chirped gratings

Often, a chirped grating is described as an aperiodic grating, which is technically correct in the strictest meaning of the term. A regular grating can be mathematically described in the following manner:

$\underline{G} = T_G(\underline{x})$ where $\underline{G}$ = Regular Grating;

T_G = Grating Transformation/Matrix function;

$\underline{x}$ = spatial dimension.

The Grating Transformation/Matrix function may be any function which produces a regular grating in the spatial domain.

A binary regular grating has a unit cell may be of equal mark-space ratio; graphically: . So, a binary grating has regions of constant refractive index having one of two possible values. A sine wave is another example of a regular grating.

However, a chirped grating can be described by a linearly-chirped or stretched regular grating thus:

$\underline{C} = T_G(\underline{x^2})$ where $\underline{C}$ = resulting chirped grating.

The spatial dimension $\underline{x}$ has undergone a simple, continuous transformation (*i.e.* it has been squared). This APGB i.e $\underline{H} \neq \underline{C}$

But an APBG cannot be so simply expressed as the regular grating transformation function T_G operating on some 'simple', continuous function of the spatial dimension $f(\underline{x})$,

$$\underline{H} \neq T_G\left(f(\underline{x})\right)$$

[*n.b.* for the binary case, such a function $f(\underline{x})$ can be found - in general being a polynomial of an order comparable with the number of elements in the APBG $\underline{H}$. However, that is not a simple function, in comparison with the chirped case, in which it is merely a 2[nd] order polynomial. Slowly-varying gratings are often characterised by a low-order polynomial, e.g. a chirped grating.].

(2) Superposition of a small number of regular gratings

Likewise, an APBG grating is a structure which cannot be expressed as a limited summation of regular gratings of various spatial frequencies:

$$\underline{H} \neq \sum_{i}^{N} a_i \underline{G}_i \qquad \text{where } a_i = \text{amplitude}$$

$\underline{G}_i$ = regular grating of i^{th} spatial frequency

For example the superposition of two gratings of similar but not identical frequencies will produce a "beat" variation

at the difference frequency. A similar effect will occur with the superposition of, for example, three or four frequencies.

Further an APBG does not include grating derived by taking the superposition of a number of regular gratings and quantising the resultant grating function to a small number of levels, for example, generating a binary grating by thresholding the said resultant grating function. The binary grating will typically have regions with few changes of level corresponding to nodes of the envelope of the resultant of the superposition interspersed with regions of regular changes of the level the period of which increases towards the antinodes of the envelope function.

(3) Concatenated regular gratings

Likewise, an APBG grating is a structure which cannot be simply expressed as a set of concatenated regular gratings of varying spatial frequency:

$$\underline{H} \neq [\underline{G}_1, \underline{G}_2, \underline{G}_3, \cdots, \underline{G}_i, \cdots, \underline{G}_N]$$

where $\underline{G}_i$ = i^{th} regular grating.

Each $\underline{G}_i$ is, of course, not infinite in extent but is windowed having a beginning and an end.

(4) Apodised slowly varying gratings

An apodised grating $A(\underline{x})$ can be characterised by multiplication of the basic structure with a slowly-varying windowing-function $W(x)$, such as a raised-cosine, or a Gaussian function. The resulting apodised grating will often be technically aperiodic, and is mathematically described as:

$A(\underline{x}) = W(\underline{x}) \cdot \underline{G}$ for an apodised regular grating,

$A(\underline{x}) = W(\underline{x}) \cdot \underline{C}$ for an apodised chirped grating

$A(\underline{x}) = W(\underline{x}) \cdot T_G(f(\underline{x}))$ for an apodised slowly-varying grating structure

An APBG or longitudinal hologram $\underline{H}$ requires a special Hologram Transformation/Matrix function T_H to produce the aperiodic structure in the spatial domain $\underline{x}$, such that in general we have:

$$\underline{H} = T_H(\underline{x})$$

The resulting hologram may be in general characterised as fast-varying.

We thus distinguish between an overall aperiodic (slowly-varying) structure resulting from the apodisation of a periodic structure, and an intrinsically aperiodic (fast-varying) structure such as an APBG. Naturally, it may be desirable to apodise APBG structures using a standard windowing function, to yield an apodised structure mathematically described as:

$A(\underline{x}) = W(\underline{x}) \cdot \underline{H}$ for an APBG structure.

The Fourier-Transform (FT) of an APBG structure will reveal its spectral distribution; i.e., the spatial period components which make it up. We have discovered that the transmission function of an APBG, be it used, for example, for grating-assisted coupling, as a photonic bandgap crystal, filter, or within Mach-Zehnder configuration, is closely related to its spectral distribution; that is, the Fourier Transform of its spatial structure. Hence, an APBG is best designed by tailoring its spectral distribution (or the FT of its spatial distribution) to yield the desired spectral response. Superficially, that appears easy, as the required

spatial distribution is thus merely the inverse FT (which is of course, equivalent to the FT)of the desired spectral response. However, the FT of a spectral distribution function will tend to yield a complex spatial distribution (i.e. containing both real and imaginary components). That is equivalent to a permittivity distribution containing both absorptive components (i.e. imaginary refractive index) and dielectric components (i.e. real refractive index), which is difficult to realise in practice.

The present invention arises from the realisation that generally only the *modulus* of the spectral distribution is of interest (e.g. for power equalisation, filtering, the existence of certain spatial periods etc.) and that its phase characteristic is of negligible importance (N.B. that is not the case for APBGs designed for dispersion compensation, where the dispersion characteristic is given by the second differential of the phase characteristic: see below). If the phase characteristic/response is allowed to be a degree of freedom, then a spatial distribution can be designed, which preferably consists only of a real or an imaginary component. The FT of that spatial distribution will yield a spectral distribution with the desired amplitude distribution, but an arbitrary phase distribution. One aspect of the invention

lies in providing a suitable spatial distribution, which is preferably purely real or purely imaginary, and yields the desired spectral response.

The two constraints in the calculation are on each side of the FT. The first constraint is the actual amplitude characteristic of the spectral distribution, while the second constraint is that the required spatial characteristic is preferably either purely real or purely imaginary. That allows simple fabrication because the real and imaginary material characteristics are usually controlled in different ways. Together, those two constraints make calculation of the required spatial characteristic a non-deterministic problem. It can be solved using optimisation algorithms such as simulated annealing (which is what we have used), error-diffusion, genetic algorithms etc.

In addition, we have discovered that often we can put a further constraint on the calculation, without unduly affecting the efficacy or functionality of the resulting APBG solution. That further constraint is to make the required spatial characteristic *binary* in nature. A binary spatial characteristic has the immediate advantage of being much simpler to fabricate, compared with a continuous spatial

characteristic, while still yielding all the desired functionalities inherent to an APBG.

Naturally, other multi-level (*M*-ary), or discretised spatial characteristic solutions can also be employed to make an APBG.

For functionalities such as dispersion compensation, where the phase characteristic of the spectral distribution is important, we need to introduce an additional constraint into the calculation. Instead of just desiring a certain magnitude of the spectral distribution response, we are now interested in both the real and imaginary amplitude characteristics respectively, both of which we try to tailor. However, the phase characteristic is not completely specified but is merely constrained to have a particular second derivative. The tangent of the phase characteristic is merely the ratio of the imaginary amplitude characteristic to the real amplitude characteristic. To achieve a reasonably effective solution, we may have to relax the constraint of a binary spatial characteristic, and allow it to become multi-level (*M*-ary), or continuous. It is important to note, however, that ultimately, we are still tailoring the

amplitude of the spectral response, rather than the phase directly.

Preferred features of the invention are set out in the dependent claims.

One way to test whether a particular grating could have been made by a method according to the invention would be to compare the response characteristic of the grating in question with the idealised function to which it corresponds (which might be, for example, a low-pass filter). If the response characteristic is sufficiently close to the idealised function for the grating to have been accepted had it been generated during the optimisation process, then it is reasonable to assume that the grating could have been designed using that process.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings of which:

Fig. 1 shows ((a) to (f)) structures of gratings having various single bandgap frequencies;

Fig. 2 shows (i) experimental and (ii) theoretical (from Fourier Transform theory) single bandgap spectra for APBGs of Figs. 1a to 1f;

Fig. 3 shows examples of two APBGs ((g), (h)) designed to exhibit multiple bandgap functionality, at 2.8 GHz and 3.6 GHz.

Fig. 4 shows experimental and theoretical results for (i) APBG (g) and (ii) APBG (h), exhibiting multiple bandgaps.

Fig. 5 is a flowchart illustrating the use of an optimisation algorithm (simulated annealing) to carry out the invention.

Fig. 6 shows various desirable simple filter characteristics:

(a) high pass (b) pass band

(c) notch (d) low pass

Fig. 7 shows further desirable filters:

(a) apodised passband

(b) pass-band with flattened passbands

Fig. 8 shows still further filter characteristics:

(a) uniform comb

(b) add/drop multiplexing

(c) equalisation

Fig. 9 shows an example filter characteristic for multi-wavelength dispersion compensation;

Fig. 10 shows an aperiodic dielectric stack, having:

(a) two refractive indices (binary); and

(b) multiple refractive indices

Fig. 11 shows an aperiodic fibre Bragg grating, being:

(a) a binary grating; and

(b) a multiple refractive index grating

Fig. 12 shows aperiodic DFB/DBR ribbed waveguiding/stripline structures:

(a) binary structure

(b) multiple heights structure

Fig. 13 shows aperiodic DFB/DBR waveguiding/stripline structures:

(a) binary structure

(b) multiple refractive index structure

Fig. 14 shows programmable APBG structures:

(a) multiple voltages

(b) single voltage

Fig. 15 shows a magnetic APBG filter, with aperiodically orientated (ferromagnetic) dipoles;

Fig. 16 shows aperiodically-poled non-linear material, (for example, aperiodically-poled lithium niobate):

(a) unidirectional

(b) bidirectional

Fig. 17 shows an APBG within a non-linear loop mirror/TOAD configuration, for multi-wavelength, high-speed optical time-domain signal processing, in five configurations, labelled (a) - (e).

Fig. 18 shows an APBG within Mach-Zehnder configurations:

(a) unidirectional

(b) bidirectional

(c) different APBG in each arm of MZ

(d) programmable APBG within MZ

(e) non-linear material APBG within MZ, with generated frequencies

Fig. 19 shows aperiodic-grating assisted couplers:

(a) uni-directional, passive coupling

(b) bidirectional, passive coupling

(c) programmable coupling

(d) non-linear material APBG within coupler, with generated frequencies

Fig. 20 shows a (asymmetric) Fabry-Perot style cavity fibre laser;

Fig. 21 shows a generic fibre ring laser;

Fig. 22 shows a distributed feedback semiconductor laser diode, employing one or more APBG

structures in place of regular Bragg grating reflectors;

Fig. 23 shows a VCSEL employing one or more APBG dielectric stacks; and

Fig. 24 shows a generic APBG lattice or superlattice having different atomic/molecular layers or multi-layers

We have performed an experiment at microwave frequencies, rather than optical frequencies, since that is simpler. A microwave source was used, tuneable from 2Ghz to 4GHz; hence with wavelengths varying from 150mm to 75mm respectively in free space. The length of the binary APBG was close to 325mm, and perspex (refractive index n_2=1.37) was used to cause the perturbation in refractive index, and hence backward coupling. Basic units consisting of an 18.8mm length of air (refractive index, n_1=1) and an associated 13.7mm (~18.8mm/n_2) length of Perspex were used to construct the APBGs. Each basic unit was thus of the same optical path length.

Taken together, the smallest spatial period in a grating could thus be a base cell of length 32.5mm, consisting of a unit length of air and a unit length of Perspex. That base

cell could then be repeated 10 times within the 325mm length of the transmission line, as shown in figure 1a.

A spatial period Λ will reflect wavelengths given by $\Lambda = (2m-1)\frac{\lambda}{2}$, where m is the grating order, given by m = 1 in this case. However, the grating was made of materials with very different refractive indices and so that formula could not be used directly. Rather, it was necessary to consider the spatial period Λ', given in terms of optical path length; i.e., as if both materials had the same refractive index (but still had the same reflection at their interface). In that case, (assuming $n_1=n_2=1$), Λ' = 2 x 18.8 mm = 37.6 mm. The wavelength of maximum reflection (and hence minimum transmission) was thus be $\lambda = 2\Lambda'$ = 75.2 mm, corresponding to a bandgap frequency of $f = c/\lambda$ = 4.0GHz.

The next available regular grating, using the same sized base cells would have a spatial period of Λ' = 75.2 mm (as shown in figure 1f), and would tend to have an associated bandgap frequency of 2.0GHz,. Generally it would not be possible to tune to intermediate frequencies between 2.0 Ghz to 4.0GHz using the same dimensioned base cells. However, an aperiodic grating does allow this to happen, and the gratings

for these intermediate frequencies are shown in figures 1(b) - 1(e).

It will be noted that (a) is periodic; (b) contains regular region corresponding to granting (a) i.e. it has a repeated unit one mark and one space; (c) is periodic and again has the regular one mark and one space unit repeated; (d) is an aperiodic APGB; (e) is an APGB comprising a concatenation of two identical APGB gratings which are each longer than the wavelengths filtered, (f) is a regular grating of twice the period of (a).

It will be noted that gratings (b), (c), and (e) display some periodicity of a longer period than the period of the regular gratings (a) and (e). Grating (b) comprises two concatenated gratings of form (a); grating (c) has a period of 5 elements; and grating (e) has a period of 10 elements. Gratings (b) and (c) are thus not fast-varying aperiodic gratings according to our definition. Note, however, that the grating of (e) is, in fact, two concatenated aperiodic gratings.

The reason that a high proportion of the gratings generated in the calculation of Fig. 1 have some degree of periodicity is that the grating consists of only 20 elements, making it likely that those elements will display some

periodicity. Larger sets of grating elements will have useful combinations which do not this tendency.

Figure 2(i) depicts the measured transmission spectra of the APBG structures depicted in figures 1a-1f. Curves (a) and (f) show the transmission spectra for the regular gratings of effective spatial period 37.6mm and 75.2mm respectively. The bandgap of curve (a) in figure 2(i) is very well defined, with a centre frequency of about 4.0GHz, with the bandgap centre frequency of curve (f) predictably being at 2.0GHz, but less well defined as might be expected for a grating with only half the number of periods. Curves (b)-(e) show the bandgap being shifted in incremental steps of about 0.4GHz, between 4.0GHz and 2.0Ghz, by using more highly structured Bragg gratings. Curve (b) has a bandgap centre frequency of 3.8GHz, while (c) is at 3.4GHz, (d) is at about 2.9GHz, and curve (e) is at about 2.6GHz, agreeing well with the theoretical bandgap frequencies as depicted in figure 2(ii). The strength of the bandgap for more highly structured Bragg gratings is not as large as for a regular Bragg grating, so that the transmission at the bandgap centre frequency tends to be higher. A longer APBG with more segments would ensure a stronger bandgap. There is also a tendency for the bandgap to weaken at lower frequencies, which also agrees with the theoretical prediction.

A Bragg grating can also be designed to exhibit multiple bandgaps. Examples of two such APBGs are shown in figure 3, and both have been designed to exhibit bandgaps at 2.8GHz and 3.6GHz. Each APBG has been designed to provide the same functionality, as afforded individually by the APBGs shown in figures 1(b) and 1(d). The resulting transmission spectra for the two APBGs are depicted in figure 4, and show that the corresponding bandgap centre frequencies lie at about 2.8GHz and 3.7GHz, which while not exactly matching the designed bandgap frequencies of 2.8 GHz and 3.6 GHz, still shows close correspondence. Because the APBG is having to do more 'work', in the sense that it is trying to produce 2 bandgaps, rather than just one, the resulting bandgaps tend to be weaker than those shown in figures 2b and 2d. There also appears to be additional 'parasitic' bandgaps at 2.4GHz for APBG(g) and 3.4GHz for APBG(h). Those are probably due to additional parasitic resonance between spatial components of the APBGs at those frequencies and the experimental waveguide apparatus. Of interest to note is that the two APBGs have been designed to ostensibly exhibit the same functionality (or transmission spectra), but the design process has yielded two completely different candidate APBGs. Both APBGs have the same primary spectral response (i.e. bandgaps at about the designed frequencies of 2.8 and 3.6GHz), but each has

slightly different parasitic properties. This illustrates the fact that the solution-space of APBGs is very large and contains many candidate functions, each with a similar Fourier Transform characteristic.

Use of an optimisation algorithm suitable for carrying out the invention is depicted schematically in Fig. 5. In this example, the optimisation algorithm is simulated annealing, which is a well-known optimisation algorithm.

Annealing is a process in which a material is strengthened by the smoothing out of dislocations in its structure. The material is heated up and then slowly cooled down. The heating causes atoms forming dislocations in the material to be excited out of local potential energy minima; cooling down slowly causes them to be redistributed smoothly, with minimal dislocations. If the cooling is too fast, dislocations will be "frozen" into the material.

Simulated annealing mimics the annealing process. A cost-function takes the place of potential energy. The aim of the process is to locate a global minimum in cost space, by randomly "hopping" solutions around (a "hot" system) and then gradually "cooling" the system by reducing the size of the random hops. If the cooling rate is chosen correctly, the solution will hopping into the global minimum whilst the system is hot and be kept there as the system cools.

The optimisation procedure depicted in Fig. 5 comprises the following steps:

(a) the target filtering function $T(\lambda)$ is selected;

(b) a random grating structure $H(x)$ is generated;

(c) a value is assigned to the initial "temperature" T of the simulated annealing, the rate of cooling alpha and the number of iterations N is set;

(d) the Fourier Transform (FT) of the grating structure is calculated, giving $h(\lambda) = FT[H(x)]$;

(e) the FT of the grating structure is compared with the target function, by calculation of the cost function (i.e., $C=\Sigma(T-h)^2$);

(f) an element in the grating is randomly changed to make a new grating, $H_1(x)$;

(g) the FT of the new grating is calculated, giving $h_1(\lambda) = FT[H_1(x)]$;

(h) a cost function is calculated for the new grating (i.e., $C_1=\Sigma(T-h_1)^2$);

(i) the cost function for the new grating is compared with the cost function for the previous grating:

(1) if $C_1 < C$, then the new grating is accepted and $H(x)$ is redefined (i.e., $H(x)=H_1(x)$ and $C=C_1$);-

(2) if $C_1 >= C$, then a random number R between 0 and 1 is calculated; if $\exp[(C-C_1/T]>R$ then the

new grating is accepted and $H(x)$ is redefined (i.e., $H(x)=H_1(x)$ and $C=C_1$); otherwise the new grating H_1 is abandoned and the changed element is returned to its previous state - another random change is made to the grating and steps (f) to (i) are repeated;

(j) once a new grating has been accepted, if the number of iterations which have taken place has not yet reached N, another random change is made to the grating and steps (f) to (i) are repeated;

(k) if the FT of the grating $h(\lambda)$ is sufficiently close to the target function $T(\lambda)$, the grating is accepted as having been optimised; otherwise, the simulated annealing is "cooled down" slightly, by reducing the temperature T by the factor alpha, and the iteration count is set back to zero. The rate of cooling alpha is usually ket constant througout the annealing. If after further loops there is no change in $h(\lambda)$ i.e. the temperature is now too cold for further change) the process is stopped (not illustrated).

In the case of calculating a grating structure for filtering light the target function is the reflectivity spectrum and the Fourier transform of grating structure performed in the simulated annealing is in detail as follows:

$$\rho(\beta) \approx \tanh\left\{\left|\frac{1}{4\bar{n}^2}\int_{-\infty}^{\infty}\frac{\partial\varepsilon_r(z)}{\partial z}e^{j2\beta z}dz\right|\right\}$$

Where $\rho(\beta)$ is the reflectivity spectrum, $\bar{n}$ is the average refractive index, $\varepsilon_r(z)$ is the relative permittivity distribution, $\beta = \frac{\bar{n}2\pi}{\lambda}$ is the propagation constant, and z is the spatial coordinate.

The spatial derivative of the relative permittivity is integrated because it is changes in that which scatters light; the tanh function scales the result of the integration appropriately.

In the following pages we shall describe the large variety of applications where APBG structures can be employed. For clarity we have divided the applications into four main areas: filters and related devices for free-space and guided electromagnetic waves including integrated optics; non-linear applications including optical signal processing; laser (maser) configurations; and more general "band engineering" of solid state devices. It should be emphasised that APBG structures can be both 2D and 3D in nature, although many of the applications highlighted tend to only require 1D APBG structures. A 1D APBG structure is one in which light emanating from a point sees the structure in one direction (along a line). A 2D APBG structure is one in which light emanating from a point sees the structure in all directions in a plane. A 3D APBG structure is one in which light emanating from a point sees the structure in all

directions in a plane. A 3D APBG structure is one in which light emanating from a point sees the structure in all directions in space. "Seeing" the structure means that the light is affected by the structure in its direction of propagation. In wave guides, for example, the light has significant component of the wavevector across the guide as well as along and so in that sense is propagating across as well as along the guide.

Filters

Examples of desired filtering characteristics

The use of APBGs allows tailored filter responses to be achieved in a far more flexible manner than allowed by existing periodic or "slowly-varying" filter structures. Examples of desired characteristics are: high-pass, band-pass, notch and low-pass filters (Figs. 6(a)-(d)) with particular phase characteristics (e.g. linear-phase, nonlinear phase, phase compensation); apodised passbands and passband-flattened passbands (Fig. 7(a)-(b)); comb-like filters, segmented passbands and non-uniform response segmented passbands ((e.g. for power equalisation) (Fig.

8(a)-(c)); and single frequency and multiple frequency dispersion compensation (Fig 9). With an appropriately sized (e.g. no. of elements) APBG, the filter can also be designed to exhibit appropriate combinations of such characteristics. Higher dimensioned (i.e. 2D and 3D) APBG structures, such as aperiodic photonic crystals, can be designed to exhibit similar useful filtering properties.

Dielectric stacks

In general, quarter-wavelength dielectric stacks use integer multiples of $\lambda/4$ thickness elements, where λ is the wavelength of interest to be filtered. However, we have discovered that we are not restricted to using integer multiples of $\lambda/4$ thickness, but we can design an APBG to have continuously-varying thicknesses of elements to achieve the desired filtering function. An APBG can be designed for a specific wavelength, where the unit thicknesses are not equivalent to $\lambda/4$ thicknesses, but are some other arbitrary thickness instead; see. gratings (b) - (e) of the embodiment/experiment description given above. Naturally, APBG dielectric stacks can also be designed for multiple wavelength filtering, see gratings (g) and (h).

Figure 10 shows two embodiments of APBG "dielectric stack" filters. The first (Fig. 10(a)) is a binary aperiodic dielectric stack where only two different refractive indices are stacked in an aperiodic fashion. Figure 10(b) shows a more general APBG dielectric filter consisting of layers of various (more than two) refractive indices where the thickness and refractive index of each layer is designed to yield the overall required filter characteristic.

Aperiodic Fibre Bragg Gratings

APBGs have many applications in guided-wave devices. Optical fibre Bragg-gratings FBGs have recently received considerable attention. The use of APBG structures, (which are by their nature "fast-varying" as opposed to the already demonstrated slowly-varying non-uniform Bragg gratings, such as chirped FBGs and apodised FBGs) permits tailoring of the filter response as described above, e.g. for multi-wavelength applications. An APBG structure can be written using UV light into the core and/or the cladding of the fibre, and can consist of either just a binary structure of two different refractive indices or an APBG of multiple refractive indices, as shown in Figs. 11(a)-(b).

Waveguiding Structures

Waveguides can also have APBG structures incorporated in their design. The APBG structure is caused by some aperiodic disturbance in the permittivity or refractive index. This can be achieved by ribbed waveguide structures, where the effective refractive index is controlled by the height of the material (which may be a dielectric or a metal) above the waveguide. This can be either binary or multi-level in nature, as shown in Figs. 12(a)-(b). Alternatively, different dopants or doping levels can be incorporated into waveguide or strip line to achieve the APBG structure in the refractive index, as shown in Figs. 13(a)-(b).

The APBG structure can also be made dynamic/reconfigurable by causing the refractive index to change due to an applied voltage, via, for example, a thermo-optic or electro-optic effect. An inter-digitated set of electrodes, each controlled by an individual voltage can be placed upon the waveguide to create an APBG structure in the refractive index of the waveguide. The electrodes could be of different widths. The APBG structure could be binary if only 2 different voltages are applied across the ensemble of electrodes, or multi-level if variable voltages are applied

to the electrodes, as depicted in Fig. 14(a). A shaped, comb-like electrode with variable thickness arms can be employed to create a fixed APBG structure, which can be turned on or off, or yield variable bandgap strengths, according to the single voltage applied to it. Such an arrangement is illustrated in Fig. 14(b).

Magnetic APBG Filter

The use of APBG filters to yield a desired response for an electrical-field is equally applicable for a magnetic-field. The same principle of operation applies. Figure 15 depicts a binary APBG structure consisting of an array of dipoles, whose north and south poles are aligned to yield an aperiodic structure. An electromagnetic wave incident on the structure will be filtered according to the APBG designed transfer response.

Non-Linear Optical Applications

Aperiodically-Poled Non-Linear Materials (APNLMs)

Periodically-poled Lithium Niobate (PPLN) is now a well established method for enhancing the non-linear effect

inherent to Lithium Niobate, via the technique of phase-matching. The grating induced by the periodic poling in the non-linear material acts as a photonic bandgap (PBG) for a small range of wavelengths centred on a 'signal' wavelength λ_s. A pump wavelength λ_p, also travels through the PPLN, but is not resonant with the PBG, so that it is not affected by it. The PBG effectively slows the signal wavelength λ_s, so that it travels through the material at the same speed as the pump wavelength λ_p, so keeping them in phase with each other. Thus they are (quasi-)phase-matched. Alternatively, λ_p could be slowed. Since they do not drift apart from each other, there is a strong interaction between the pump and signal throughout the length of the PPLN, which enhances the non-linear interaction between them. The non-linear effects (such as χ^2, χ^3 non-linearities) will typically generate signals at additional wavelengths $\Sigma\lambda_g$, in processes such as 3- and 4-wave-mixing,or (e.g. 2nd and 3rd) harmonic generation. These non-linearities can be used to make optical parametric amplifiers (OPAs) and optical parametric oscillators (OPOs). There are other non-linearities such as the Kerr effect whose effect can also be enhanced using periodic-poling.

Aperiodic photonic bandgap structures can also be employed within non-linear materials to quasi-phase-match multiple wavelengths with each other, with multiple generated wavelengths, and with multiple pump wavelengths. Each of the wavelengths within an arbitrarily chosen set of wavelengths can be quasi-phase-matched with each other. Arbitrary, multiple sets of wavelengths can be adopted, and the APBG designed so that each set is essentially independent (i.e. non-phase-matched) with respect to the others.

Since the APBG can be designed to have bandgaps and bandpasses at arbitrary multiple wavelengths, it can be used to inhibit/suppress selected wavelengths, such as the pump wavelength(s), signal wavelength(s) and generated wavelengths. For example, An APBG structure might be used to enhance the 4-wave-mixing non-linear effect between a pump signal and various signal wavelengths, and to suppress the unwanted generated harmonics.

Figure 16(a), shows an aperiodically-poled non-linear material, such as aperiodically-poled Lithium Niobate (APLN), with a set of pump wavelengths $\Sigma\lambda_p$, a set of input signal wavelengths $\Sigma\lambda_i$, and the various sets of wavelengths arising

due to the APBG structure and the material non-linearities. There will be a set of output wavelengths $\Sigma\lambda_o$, e.g. modified or unmodified versions of the input/pump wavelengths; a set of generated (harmonic) wavelengths $\Sigma\lambda_g$, due to the material non-linearities; and a set of reflected wavelengths $\Sigma\lambda_r$, corresponding to input/pump/generated wavelengths which cannot propagate through the APBG and so are reflected back. The relative strengths of all the wavelengths can also be controlled by suitable design of the APBG. Figure 16(b), shows how an aperiodially-poled non-linear material may be used in a 'bi-directional' manner, as opposed to the 'uni-directional' manner of Figure 16(a). Applications include (multi-)wavelength conversion, optical (multi-)wavelength regeneration, optical (multi-)wavelength signal re-timing.

Multi-wavelength, Optical Time Domain Signal Processing

Single wavelength, high-speed, optical time domain processing is now well established using the TOAD, a non-linear optical loop mirror (NOLM) containing a spatially asymmetric semiconductor optical amplifier (SOA). An input signal pulse is split into two equal components within the NOLM, and travel counterwise to each other. In the absence of

any perturbing influence, by the principle of reciprocity, they will remain in phase with each other and interfere positively at the coupler, to emerge from the input arm of the NOLM as if it had been reflected. However, when a pump (switching) signal pulse is injected into the NOLM from the side, it causes the non-linear Kerr effect to induce a relative phase change in one of the components of the signal, but not the other component. This is due to the spatial asymmetry of the SOA. If the phase change is carefully controlled, the two signal components will interfere destructively at the coupler, and emerge from the alternative arm of the NOLM as a transmitted signal.

Introducing an APBG structure within the NOLM allows multi-wavelength optical time domain signal processing. Figure 17(a) shows a TOAD structure with a spatially-asymmetric (determined by the displacement from symmetry, d_1) aperiodically-poled SOA acting as an APBG with amplification properties. At its simplest, the configuration will only allow certain switching wavelengths to pass through the SOA, to cause switching of the input signal pulse. Other wavelengths will be simply reflected. This introduces an element of wavelength selectivity within the TOAD, so that only certain wavelengths can be used to switch the signal.

Alternatively, the APBG structure can be used to reflect the input signal pulse components, so that they are reflected back to the coupler, rather than travelling all the way around the NOLM. At best, the APBG structure is placed spatially-symmetrically within the TOAD, as shown in figure 17(b), where the displacement $d_2=0$. In such a fashion, only signals of certain wavelengths can be switched. Naturally, both relative displacements d_2 and d_3 of the APBG and SOA respectively are degrees of freedom which can be adjusted to enhance functionality. A combination of aperiodically-poled SOA and APBG (i.e. a combination of figures 17(a) and 17(b)) can be employed to allow wavelength selectivity in both the switching and input signal pulses.

Figure 17(c) shows a TOAD configuration employing an aperiodically-poled non-linear material (APNLM) in place of the SOA. Figure 17(d) shows a TOAD configuration employing an APNLM in place of the SOA, in conjunction with a passive APBG structure, while figure 17(e) shows 2 passive APBG structures within the NOLM. As is obvious from the discussion on APNLMs, these systems have many degrees of freedom, in terms of input, switching/pump, generated, output wavelengths, and the relative strengths of each of these. All of the

configurations 17(a-e) can be used in combination with each other to achieve complex multi-wavelength optical time domain signal processing. All APBG structures depicted schematically in figures 17(a-e) can either be separate components, or written directly into the optical fibre.

Mach-Zehnder Configurations

The Mach-Zehnder (MZ) interferometer is another important technology for optical switching, and APBGs also find application in it. Figure 18(a) shows a simple MZ schematic, with an APBG structure placed within one of its arms. The APBG structure can be designed to change the relative phase of wavelengths by slowing the wavelengths down, and/or to reflect the wavelengths. Without any phase changes or reflections, a wavelength would be split equally into the 2 arms of the MZ, and then constructively recombine at the far end to emerge from the 'bar' port. However, by introducing a suitable phase change (typically $\pi/2$) the wavelength will emerge from the other 'cross' port, and can be considered to have been switched. The APBG can be designed to cause various arbitrary wavelengths to experience the required $\pi/2$ phase change, and so be switched, while other wavelengths will remain un-switched. Likewise, the APBG can

also be designed to reflect certain wavelengths and impart a relative phase change onto them, so that they emerge either from the original input port, or the alternative input port to the MZ. Other intermdiate phase-changes, and degrees of reflectivities will cause the wavelengths to appear at the 4 ports of the device with varying degrees of strength. Figure 18(b) shows that such a configuration can also be used bi-directionally.

Figure 18(c) shows a MZ configuration with an APBG in each arm. Each APBG can be identical, or different to achieve a differential-type filtering operation. Figure 18(d) depicts a MZ with a programmable APBG in one of its arms. Each element of the programmable APBG can either be individually controlled, such as in figure 14(a), or controlled by a single voltage source as in figure 14(b). Figure 18(e) shows a MZ configuration with an APNLM in the arms. Alternatively, there could be just one APNLM in each of the arms, with the second arm plain or containing a passive APBG.

The APBG/APNLM structures within the MZ configuration can either be discrete components, or written into the integrated-optic waveguides.

Grating Assisted Couplers

Phase-matching is used in grating assisted couplers to cause cross-coupling, and thus switching to occur. Conventionally, a uniform (periodic) grating is written between two closely separated waveguides, each with its own modes of propagation. The grating causes coupling to occur between the modes of the first waveguide with the modes of the second waveguide, and coupled mode theory (CMT) can be used to analyse how a mode (associated with a wavelength) in one waveguide can excite a mode (associated with the same wavelength) in the second waveguide. If the parameters of the system are correctly designed (e.g. the correct grating period of the uniform grating), the power associated with the mode (i.e. wavelength) in the first waveguide can be completely resonantly coupled into the second waveguide. Hence switching has occurred. Other wavelengths will not be resonant with the grating, and so will remain unswitched. Generally, a uniform grating will tend to resonantly-couple only one wavelength (as well as weakly coupling higher harmonics of the wavelength).

Aperiodic grating structures (i.e. APBG structures) can be employed instead of a uniform grating, to resonantly-

couple multiple, arbitrary wavelengths. The APBG can be considered to consist of multiple spatial periods, each or which resonates with a wavelength to cause cross coupling. Such a configuration is shown in figure 19(a). The input wavelengths $\Sigma\lambda_i$ enter the aperiodic-grating assisted coupler, and certain wavelengths, corresponding to $\Sigma\lambda_s$ are resonantly cross-coupled into the other waveguide, and are switched. The remaining wavelengths $\Sigma\lambda_t$ remain within the 1st waveguide are simply transmitted. In addition, the APBG can also act as a photonic bandgap structure to reflect certain wavelengths $\Sigma\lambda_r$ back to the input plane, i.e. they could be reflected back to the 1st waveguide, or into the second waveguide.

Figure 19(b) shows the aperiodic-grating assisted coupler used in a bidirectional manner. Figure 19(c) illustrates that the APBG structure could be made programmable. Figure 19(d) indicates that an aperiodically-poled non-linear material (APNLM) could also be used to perform grating-assisted coupling, while generating additional wavelengths in the process, which can be designed to emerge at any one of the 4 possible ports.

Lasers

APBGs have many applications in the field of lasers. One or more APBGs can be used to define wavelength selective mirrors, which in turn can be used to define single or composite wavelength-selective resonators. When used in conjunction with an active medium, greater control of single or multiple laser wavelengths should be achievable than with conventional mirrors. It should be possible to create such mirrors both in bulk material and in waveguiding structures, such as those used, for example, in semiconductor lasers and fibre lasers. The APBG can also be designed to function as a suitable filter in optically pumped lasers, e.g. to couple the pump wavelength(s) in and out of the cavity/active medium.

Where APBGs are used in a multi-wavelength laser, each wavelength can have the same effective cavity length (or round trip time). The group-velocity/ phase characteristics of each wavelength can be tailored via the APBG to facilitate a/synchronous multi-wavelength modelocking, and to exclude other wavelengths from modelocking, so that they lase in a CW mode.

For example two APBGs can be used to create a Fabry-Perot style cavity for a fibre laser (Fig. 20), with the added functionality that the filter response can be arbitrarily designed (to be high transmission, for example) at single or multiple pump wavelengths and (to have a high-Q, for example) at single or multiple laser wavelengths. One topical application of such a device would be in (cascaded) Raman laser/ amplifiers, where typically it is required to shift the pump laser(s) through a number of Stokes shifts by creating coupled Raman lasers at each Stokes shift. Current proposals include one having many fibre Bragg gratings, each with a characteristic reflectivity at one Stokes wavelength to create a composite cavity. With appropriately designed APBG structures the same functionality could be achieved with only two APBGs.

APBGs can also be advantageously used within other laser configurations, such as rings (single or multiple, Sagnac loops, figure of 8 loops, etc.) Figure 21 depicts such a generic fibre ring laser cavity.

Semiconductor lasers widely employ grating-based wavelength selective feedback, for example in DBR, DFB and VCSEL designs. APBGs can usefuly be employed to provide such

feedback, with the added functionality as defined above. Examples of DFB and VCSEL structures incorporating ABPGs are shown in figures 22 & 23 respectively. Further functionality can be achieved, e.g. multi-wavelength conversion, multi-wavelength 3R regeneration, by concatenating suitable APBG/APNLM structures with either conventional semiconductor lasers, or APBG-modified semiconductor lasers.

Electronic Band-Gap Engineering

One of the most striking realisations about the application of APBG structures is that they are useful in modifying electronic band-gap of "new" materials, designed to have an aperiodic lattice or superlattice. We anticipate that a host of new materials and new devices should result from the application of these structures. There is already much work on periodic superlattices, for example. The use of APBG superlattices enhances the possibilities for such designs. A generic APBG lattice (or super-lattice) is depicted in figure 24.

Plane-wave (Fourier) expansions of wavefunctions are often used in current theoretical models of solid-state structures. With iterative optimisation algorithms (as

outlined above) to design aperiodic structures, material parameters, e.g. location of band minima, effective mass etc. can be tailored to yield new aperiodic materials with desirable band-structure characteristics. Other parameters such as conductivity, thermal conductivity and dielectric permittivity or magnetic permeability could also be designed into the material.

This design technique should also find applications in the fabrication of new superconducting materials in which, for example, some of the properties of boson-like Cooper-pairs can be treated in an analogous manner to photons in a photonic crystal.

Claims

1. A longitudinal grating having an aperiodic structure, wherein the grating has a selected response characteristic and any repeated unit cell in the structure is significantly longer than a characteristic length associated with the selected response characteristic.

2. A grating as claimed in claim 1, in which the structure comprises discrete grating elements of at least two different kinds.

3. A grating as claimed in claim 2, which comprises 5 or more grating elements.

4. A grating as claimed in claim 3, which comprises 20 or more grating elements.

5. A grating as claimed in any preceding claim, comprising material which has no, or a negligible, real component or no, or a negligible, imaginary component.

6. A grating as claimed in any preceding claim, in which the selected response characteristic is a spectral amplitude response and the characteristic length is a spectral amplitude cut-off wavelength.

7. A grating as claimed in claim 6, in which the spectral amplitude response includes at least one band gap.

8. A grating as claimed in claim 7, in which the spectral amplitude response includes at least two band gaps.

9. A grating as claimed in claim 7 or 8, in which the band gap is a photonic band gap.

10. A grating as claimed in claim 6, having a low-pass filter spectral amplitude response.

11. A grating as claimed in claim 6, having a band-pass filter spectral amplitude response.

12. A grating as claimed in claim 6, having a notch filter spectral amplitude response.

13. A grating as claimed in claim 6, having a high-pass filter spectral amplitude response.

14. A grating as claimed in claim 6, in which the spectral amplitude response comprises an apodised band-pass filter.

15. A grating as claimed in claim 6, in which the spectral amplitude response comprises a passband-flattened band-pass filter.

16. A grating as claimed in claim 6, in which the spectral amplitude response comprises a comb-like filter.

17. A grating as claimed in claim 6, in which the spectral amplitude response comprises a regimented band-pass filter.

18. A grating as claimed in claim 6, in which the spectral amplitude response comprises a non-uniform response segmented band-pass filter.

19. A grating as claimed in any preceding claim, having a spectral phase response which is linear.

20. A grating as claimed in any preceding claim, having a spectral phase response which is nonlinear.

21. A grating as claimed in any preceding claim which is suitable for phase compensation.

22. A grating as claimed in any preceding claim, which is suitable for single-frequency dispersion compensation.

23. A grating as claimed in any preceding claim, which is suitable for a multiple-frequency dispersion compensation.

24. A grating as claimed in claim 6, in which the spectral amplitude response comprises a combination of the response characteristics claimed in any of claims 6 to 23.

25. A grating as claimed in any of claims 1 to 24, in which the aperiodic grating structure is 2-dimensional.

26. A grating as claimed in any of claims 1 to 25 in which the aperiodic grating structure is 3-dimensional.

27. A filter comprising a grating as claimed in any of claims claim 1 to 26.

28. A dielectric stack, comprising a grating as claimed in any of claims 1 to 26.

29. A dielectric stack as claimed in claim 28, for use at a specified wavelength, comprising layers at least one of which is of an optical thickness which is not an integer multiple of one quarter of the specified wavelength.

30. A dielectric stack as claimed in claims 28 or 29, comprising two kinds of layers differing in refractive index.

31. A dielectric stack as claimed in claim 28 or 29, which comprises layers, at least three of which have refractive indices which are different from each other.

32. An optical fibre Bragg-grating, comprising a grating as claimed in any of claims 1 to 26.

33. An optical fibre Bragg-grating as claimed in claim 32, which comprises a structure of two different refractive indices.

34. An optical fibre Bragg-grating as claimed in claim 32, in which the fibre Bragg-grating comprises a structure including at least three points having different refractive indices from each other.

35. A waveguide structure comprising a grating as claimed in any of claims 1 to 26.

36. A waveguide structure as claimed in claim 35, comprising a ribbed waveguide structure.

37. A waveguide structure as claimed in claim 36, in which the ribbed waveguide structure comprises two kinds of regions differing in effective refractive indices.

38. A waveguide structure as claimed in claim 36, in which the ribbed waveguide structure comprises at least three kinds of regions each having a different effective refractive indices.

39. A waveguide structure as claimed in claim 35, which is a doped waveguide structure.

40. A waveguide structure as claimed in any of claims 35 to 39, which is a dynamic and/or reconfigurable structure, wherein the grating is arranged so that the magnitude of the relevant parameter may be altered at at least one point in the grating.

41. A waveguide structure as claimed in claim 40 in which the reconfiguration is achieved using a thermo-optic effect.

42. A waveguide structure as claimed in claim 40 in which the reconfiguration is achieved using an electro-optic effect.

43. A waveguide structure as claimed in claim 41 or 42, in which the effect is effected by inter-digitated electrodes.

44. A waveguide structure as claimed in claim 41 or 42, in which the effect is effected by a comb-like electrode.

45. A waveguide according to any of claims 35 to 44, in which the grating is along the length of the waveguide.

46. A waveguide according to any of claims 35 to 45, in which the grating is within the waveguiding region.

47. A waveguide structure according to any of claims 35 to 46, in which the waveguide is any of the following: an optical fibre, a microwave strip line, a silica on silicon planar lightwave circuit (PLC), a silicon on silica PLC, a semiconductor amplifier, a semiconductor laser.

48. A grating as claimed in any of claims 1 to 26, in which structure is in the material permittivity.

49. A grating as claimed in claim 48, in which structure is in the refractive index.

50. A grating as claimed in any of claims 1 to 26, in which structure is in the material permeability.

51. A grating as claimed in any of claims 1 to 26, in which structure is in the a magnetic property.

52. A grating as claimed in claim 51 in which the magnetic property is the orientation and/or strength of a magnetic dipole.

53. An aperiodically-poled non-linear material, comprising a grating as claimed in any of claims 1 to 26, which is employed to quasi-phase-match light at two or more wavelengths.

54. An aperiodically-poled non-linear material, comprising a grating as claimed in any of claims 1 to 26, which is employed to suppress light at one or more wavelength.

55. A non-linear optical loop mirror including a non-linear material as claimed in claim 53 or 54.

56. A non-linear optical loop mirror as claimed in claim 55, further comprising an aperiodically poled semiconductor optical amplifier.

57. A non-linear optical loop mirror including a grating according to any of claims 1 to 26.

58. A non-linear optical loop mirror according to claim 57, in which the grating comprises an aperiodically-poled semiconductor optical amplifier.

59. A Mach-Zehnder interferometer including a grating according to any of claims 1 to 26.

60. A Mach-Zehnder interferometer as claimed in claim 59, including such a grating in each of its arms.

61. A Mach-Zehnder interferometer as claimed in claim 59, including an aperiodically-poled non-linear material as claimed in claim 53 or 54.

62. A Mach-Zehnder interferometer as claimed in claim 59, including a waveguide structure as claimed in any of claims 35 to 47.

63. A Mach-Zehnder interferometer as claimed in any of claims 59 to 62, in which the grating is written onto an integrated-optic waveguide.

64. A grating-assisted coupler including a grating according to any of claims 1 to 26.

65. A grating-assisted coupler as claimed in claim 64or claim 65, which is bidirectional.

66. A grating-assisted coupler as claimed in claim 65, which is programmable.

67. A grating-assisted coupler as claimed in any of claims 64 to 66, including an aperiodically-poled non-linear material as claimed in claims 53 or 54.

68. A laser, including a grating according to any of claims 1 to 26.

69. A laser according to claim 68, in which the grating is in the laser cavity.

70. A laser according to claim 68 in which the grating is comprised in a wavelength-selective mirror.

71. A laser according to claim 70, in which the mirror allows the laser to lase at multiple wavelengths.

72. A laser according to any of claims 68 to 71, which is pulsed.

73. A laser according to any of claims 68 to 72, which can be modelocked.

74. A laser according to any of claims 68 to 73, which is a ring laser.

75. A laser according to any of claims 68 to 74, which is a semiconductor laser.

76. A laser according to claim 75 having a DBR structure.

77. A laser according to claim 75, having a DFB structure.

78. A laser according to claim 75, having VCSEL structrue.

79. A Fabry-Perot cavity, comprising at least one end mirror comprising a grating according to any of claims 1 to 26.

80. A Raman amplifier, comprising a Fabry-Perot cavity according to claim 79.

81. A Raman laser, comprising a Fabry-Perot cavity according to claim 79.

82. A material including a grating as claimed in any of claims 1 to 26, in which the grating modifies an electronic bandgap structure.

83. A material including a grating as claimed in any of claims 1 to 26, in which electronic potential has a variation controlling the selected response characteristic.

84. A material as claimed in claim 83, in which the electrical potential comprises classical scatterers.

85. A material as claimed in claim 83, in which the electrical potential comprises quantum scatterers.

86. A material as claimed in claim 84 or claim 85, in which the scatterers are positioned at the vertices of a lattice or superlattice.

87. A material as claimed in claim 86, in which the superlattice is an electronic superlattice structure.

88. A material as claimed in claim 86, in which the superlattice is a superconducting superlattice.

89. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is a band minimum.

90. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is an effective mass.

91. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is a thermal conductivity.

92. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is a dielectric permittivity.

93. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is a conductivity.

94. A material as claimed in any of claims 82 to 88, in which the selected response characteristic is a magnetic permeability.

95. A material as claimed in any of claims 82 to 94, which is a superconducting material.

96. A grating as claimed in any of claims 1 to 26, which is in or on a nonlinear medium and which enhances a nonlinear effect.

97. A grating as claimed in any of claims 1 to 26, which is in or on a nonlinear medium and in which the selected response characteristic is phase matching between at least two wavelengths and the characteristic length is an optical path length as measured in air, of $2\pi/\delta\beta$ where $\delta\beta$ is the difference between the propagation constant of two of the phase matched wavelengths.

98. Use of a grating according to claim 96 or claim 97, in any of the following applications: wavelength conversion, signal re-timing, signal regeneration, parametric amplification, applications involving second- and third-order nonlinear effects (for example, second- and third-harmonic generation or the Kerr effect), or parametric oscillators.

99. A method of making a longitudinal grating comprising: selecting a response characteristic and using an optimisation algorithm to determine a grating arrangement which closely has the selected response characteristic, wherein the grating

is aperiodic and wherein any repeated unit cell in the structure of the grating is significantly longer than a characteristic length associated with the selected response characteristic.

100. A method according to claim 99, in which the grating arrangement is varied during optimisation.

101. A method as claimed in claim 99 or 100, in which the elements of the grating are directly and individually varied.

102. A method according to any one of claim9 99 to 101, in which the response characteristic of the grating is taken during optimisation to be approximately, or is derived from, the Fourier Transform of the grating arrangement during optimisation.

103. A method according to claim 102 wherein a cost function is calculated from the selected response characteristic and the Fourier Transform or a function derived thereform.

104. A method according to any of claims 99 to 103, in which the Fourier Transform of the grating arrangement is evaluated

during optimisation to see if, or how, it differs from the selected response characteristic.

105. A method as claimed in any of claims 99 to 104, in which the optimisation algorithm is simulated annealing.

106. A method as claimed in any of claims 99 to 105, in which the optimisation algorithm is error-diffusion.

107. A longitudinal grating made using a method according to any of claims 99 to 106.

108. A longitudinal grating which could be made using a method according to any of claims 99 to 106.

109. A longitudinal grating which is aperiodic, comprising a set of concatenated, repeated base cells, at least some of which differ slightly from each other.

110. A longitudinal grating, which has a shortest period which is larger than the period of a regular binary grating which has marks and spaces of the same length as the longest constant region in the longitudinal grating.

111. A longitudinal grating as claimed in claim 110, which is aperiodic.

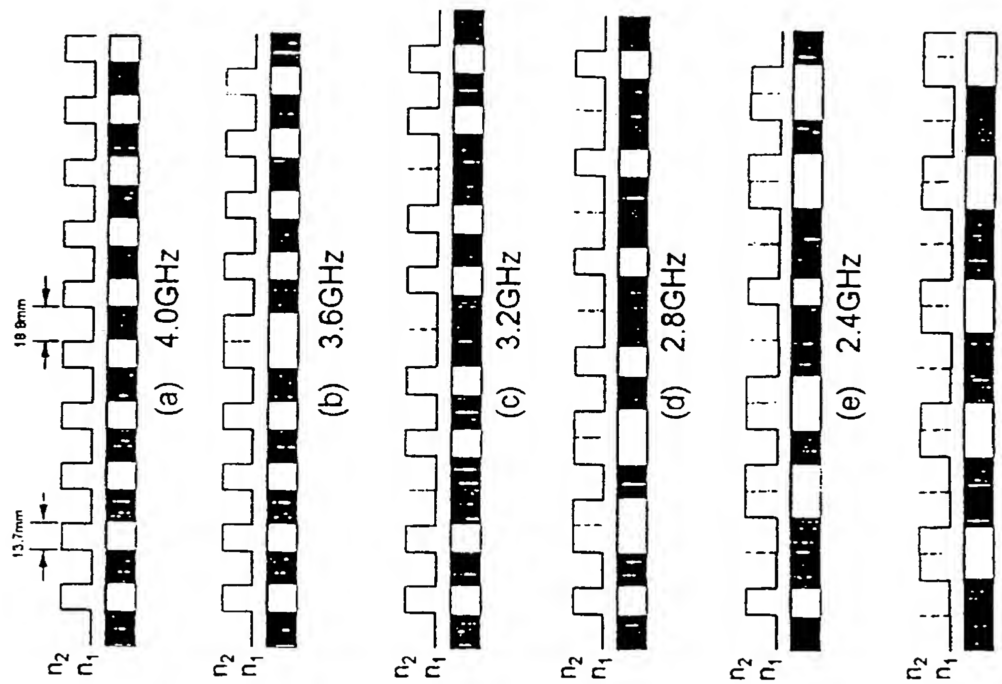
112. A longitudinal grating, comprising a plurality of concatenated gratings as claimed in any of claims 1 to 26, 48 to 52, 96 or 97 or 107 or 111.

113. A grating as claimed in claim 112, in which at least some of the aperiodic structures are identical to each other.

114. A grating as claimed in claim 113, in which all of the aperiodic structures are identical to each other.

115. A grating as claimed in claim 1 in which the structure is programmable to switch between a plurality of selected response characteristics.

Fig. 1


13.7mm
18.8mm
n_2
n_1
(a) 4.0GHz
(b) 3.6GHz
(c) 3.2GHz
(d) 2.8GHz
(e) 2.4GHz
(f) 2.0GHz

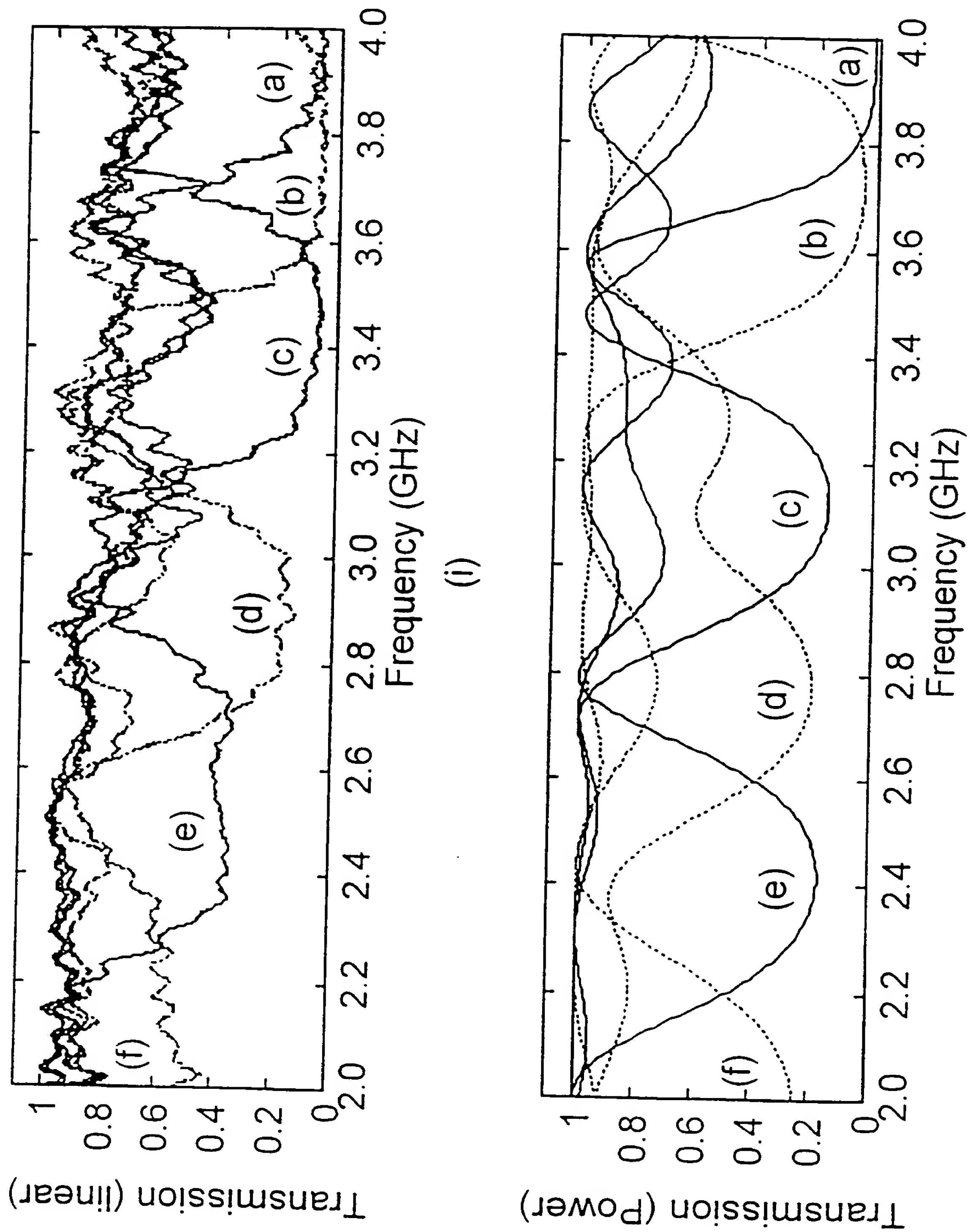

Transmission (linear)
Frequency (GHz)
(i)
(a)
(b)
(c)
(d)
(e)
(f)
Transmission (Power)
Frequency (GHz)
(ii)

Fig. 2

Fig. 3

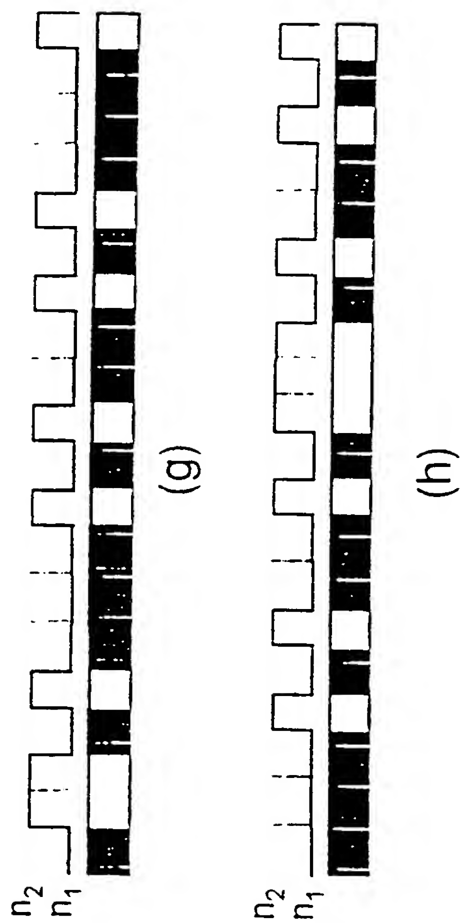


Fig. 4

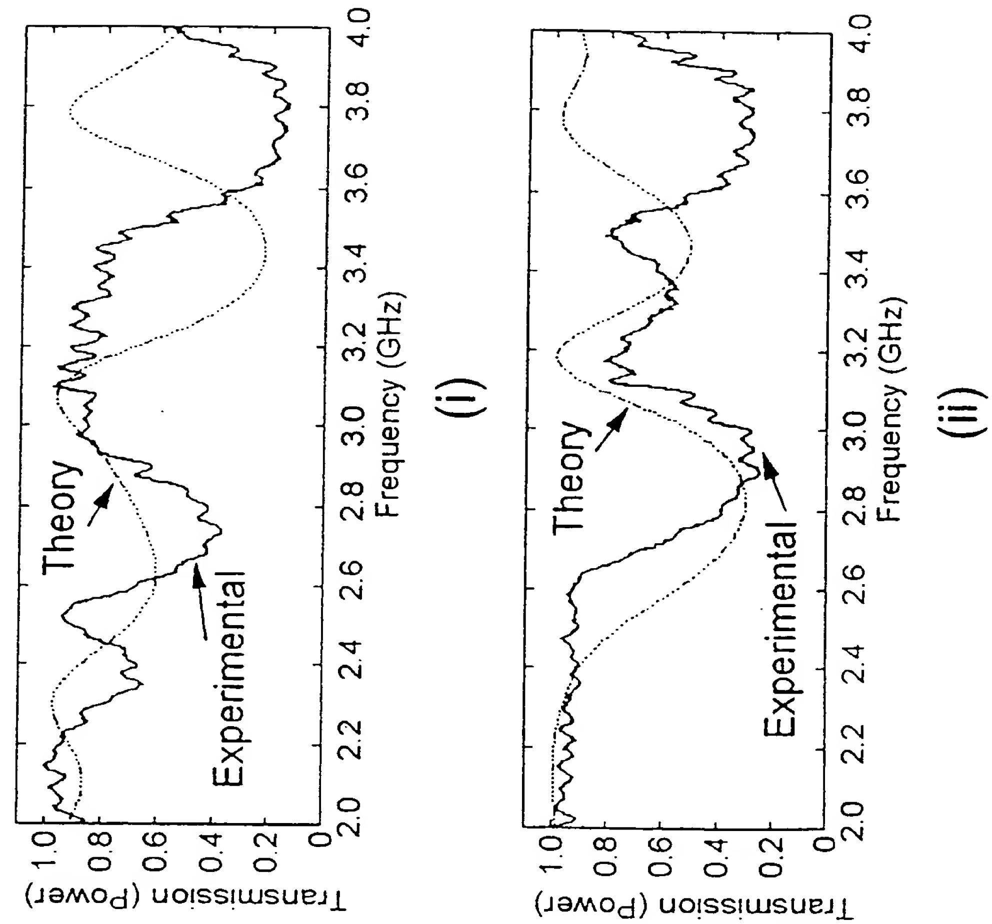
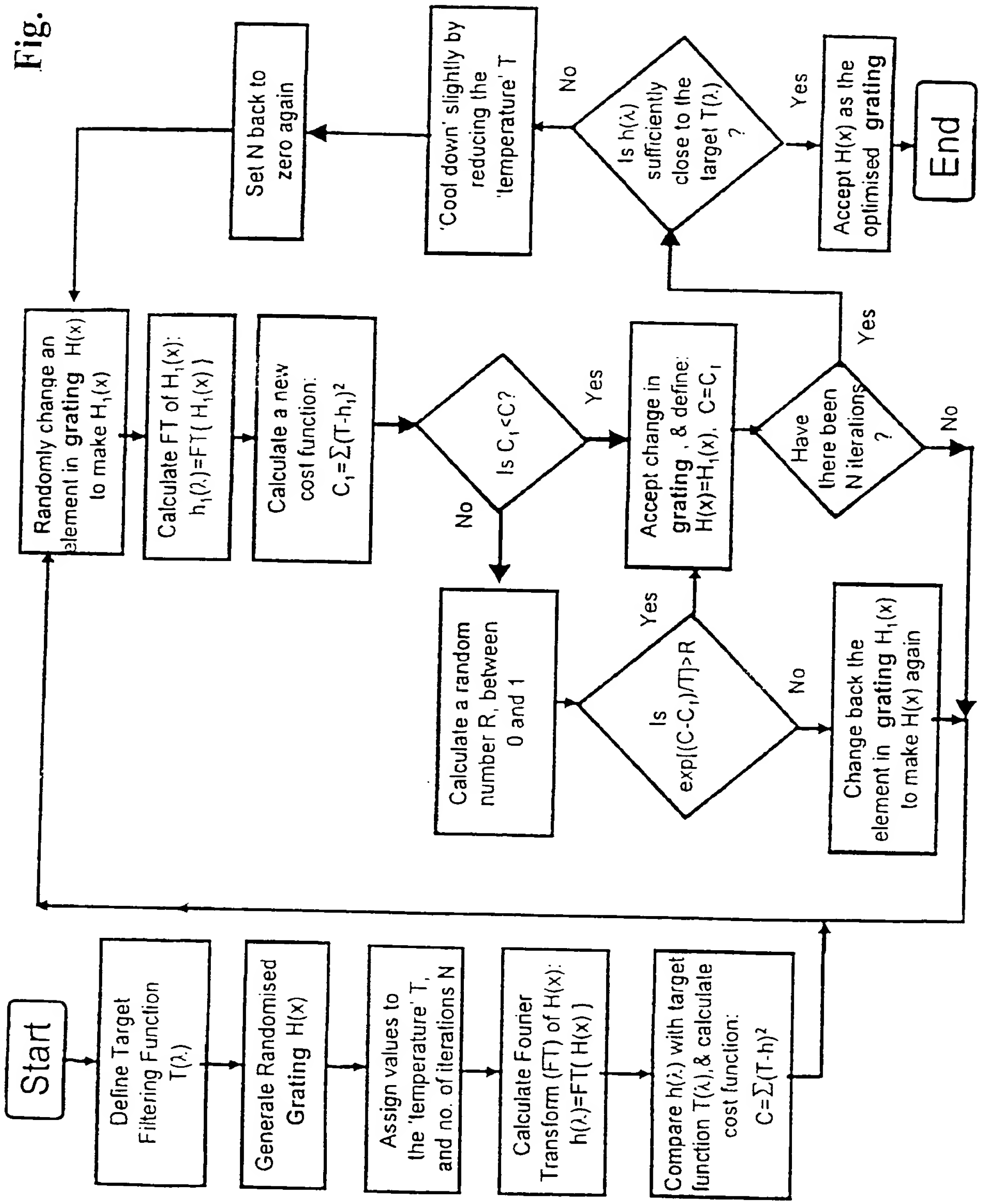

Theory
Experimental
Transmission (Power)
Frequency (GHz)
(i)
Theory
Experimental
Transmission (Power)
Frequency (GHz)
(ii)

Fig. 5


Start
Define Target Filtering Function T(λ)
Generate Randomised Grating H(x)
Assign values to the 'temperature' T, and no. of iterations N
Calculate Fourier Transform (FT) of H(x): h(λ)=FT(H(x))
Compare h(λ) with target function T(λ),& calculate cost function: C=Σ(T-h)²
Randomly change an element in grating H(x) to make H₁(x)
Calculate FT of H₁(x): h₁(λ)=FT(H₁(x))
Calculate a new cost function: C₁=Σ(T-h₁)²
Is C₁<C?
Yes
No
Calculate a random number R, between 0 and 1
Is exp[(C-C₁)/T]>R
Yes
No
Accept change in grating , & define: H(x)=H₁(x), C=C₁
Change back the element in grating H₁(x) to make H(x) again
Have there been N iterations ?
Yes
No
Is h(λ) sufficiently close to the target T(λ) ?
No
Yes
'Cool down' slightly by reducing the 'temperature' T
Set N back to zero again
Accept H(x) as the optimised grating
End

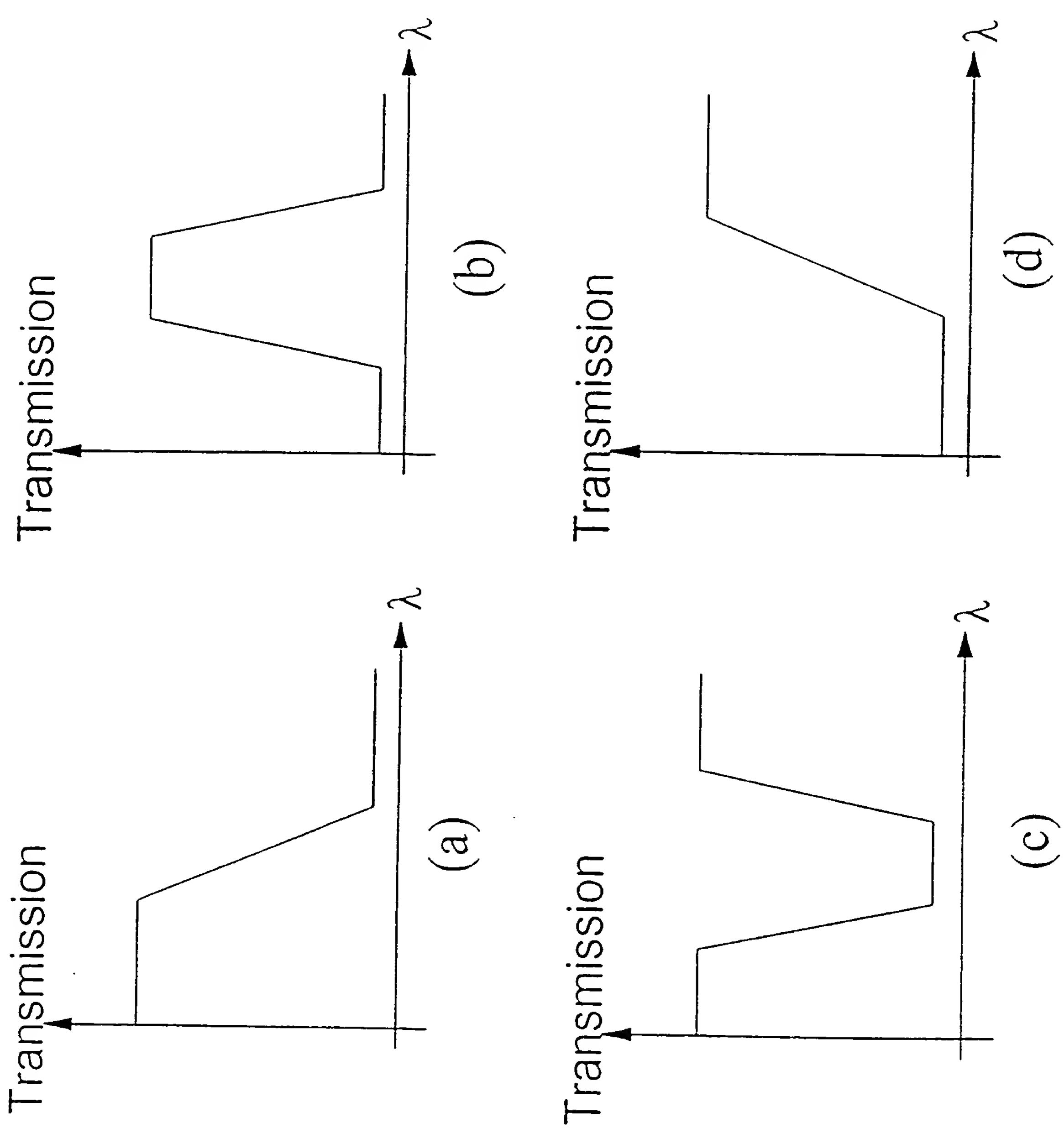

Transmission
λ
(a)
Transmission
λ
(b)
Transmission
λ
(c)
Transmission
λ
(d)

Fig. 6

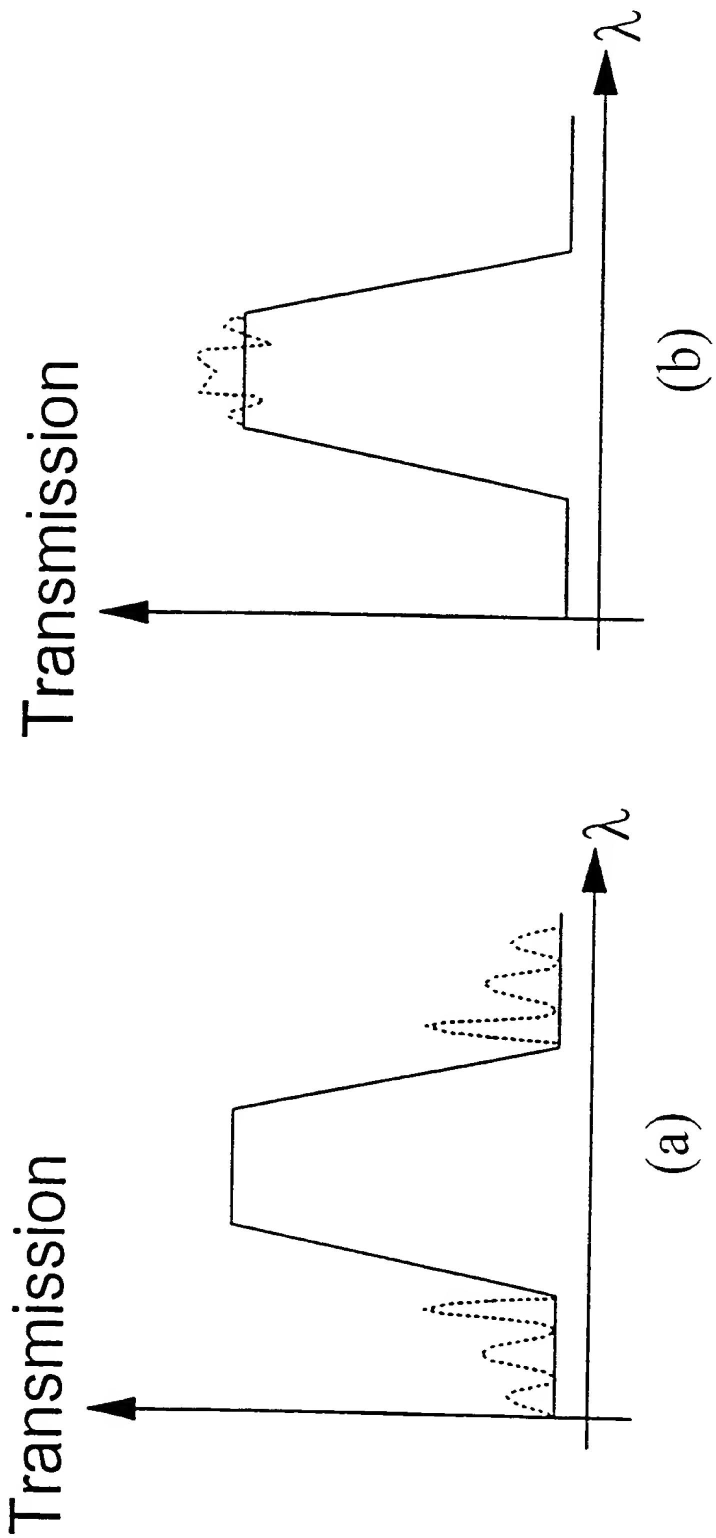


Fig. 7

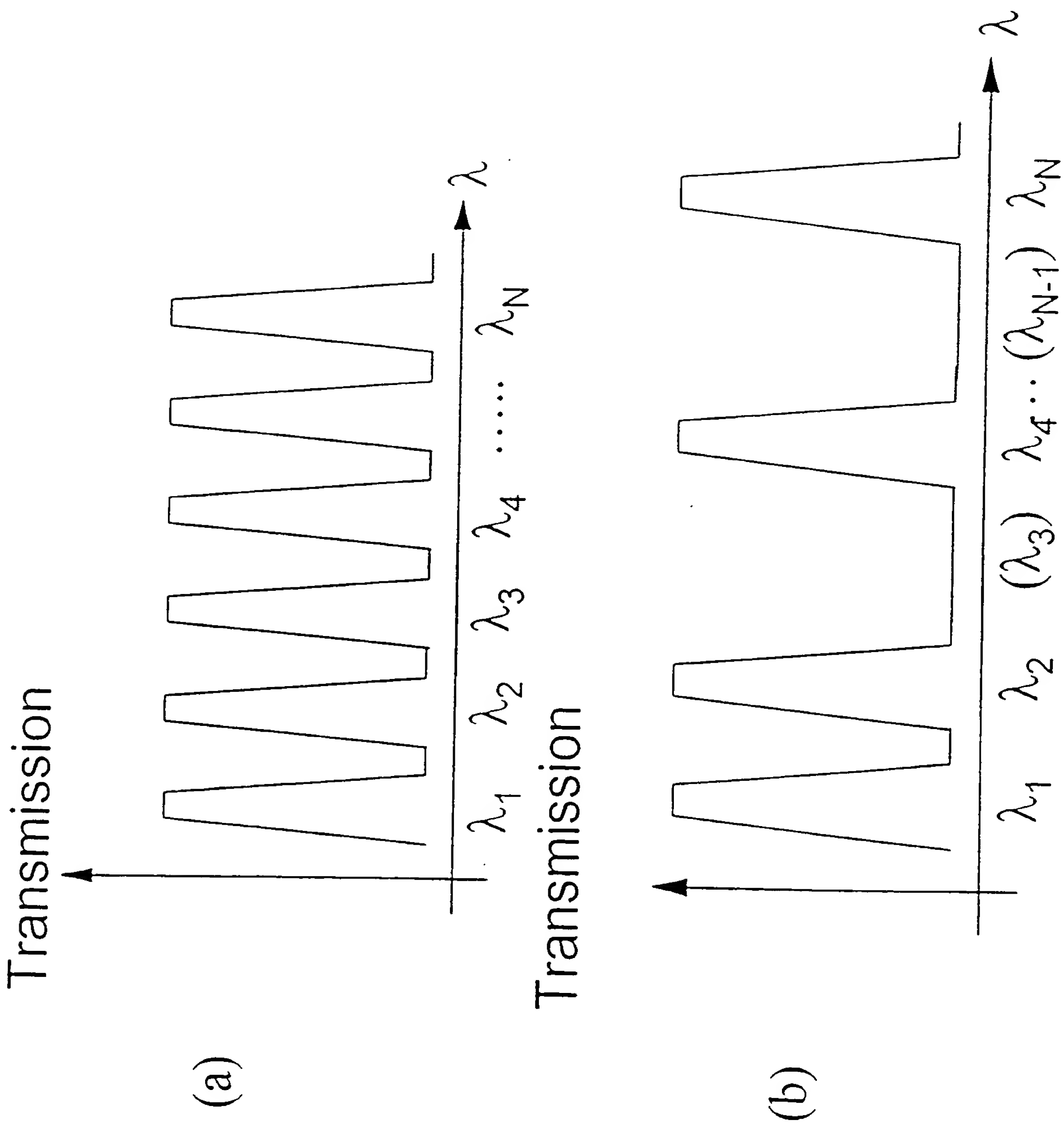

(a)
Transmission
λ_1 λ_2 λ_3 λ_4 ..... λ_N
λ
(b)
Transmission
λ_1 λ_2 (λ_3) $\lambda_4 \cdots (\lambda_{N-1})$ λ_N
λ

Fig. 8

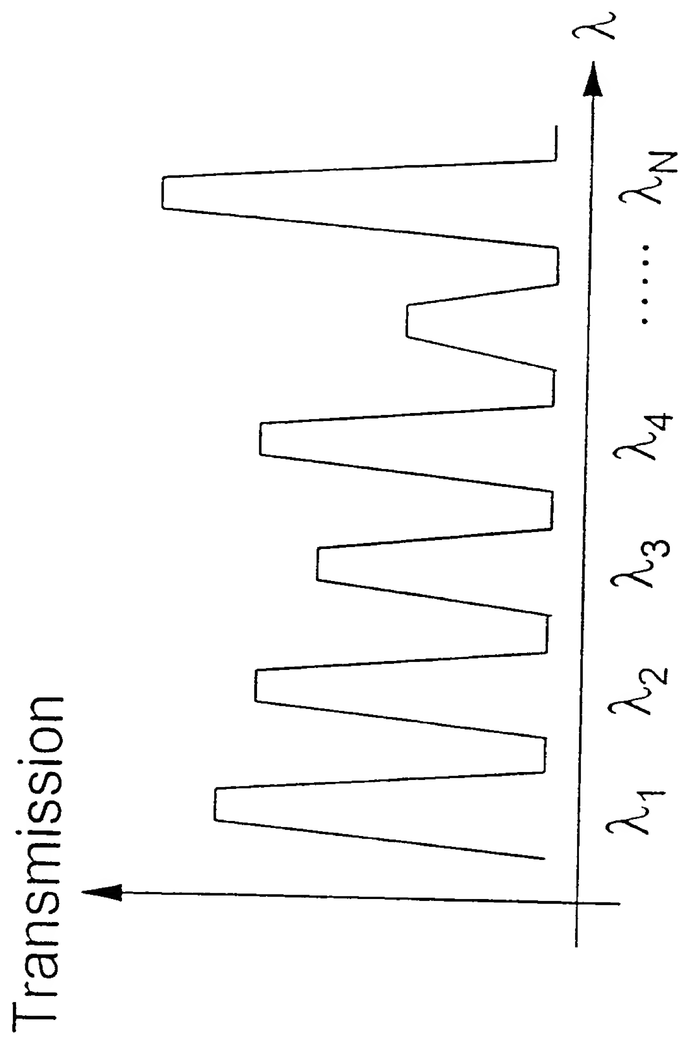

Transmission
λ
λ_1
λ_2
λ_3
λ_4
.....
λ_N

Fig. 8(c)

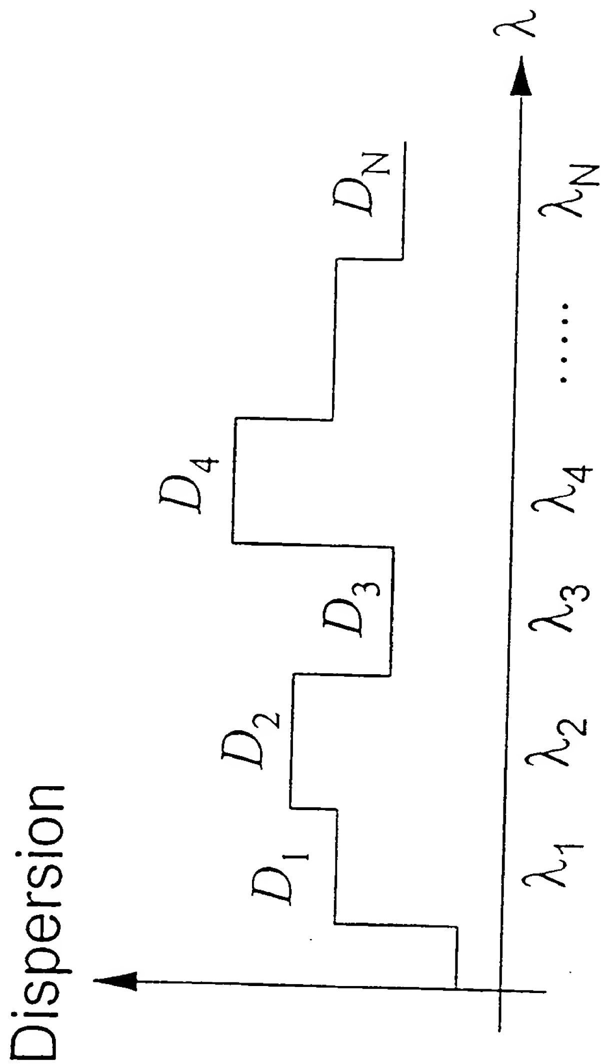

Dispersion
D_1
D_2
D_3
D_4
D_N
λ_1
λ_2
λ_3
λ_4
......
λ_N
λ

Fig. 9

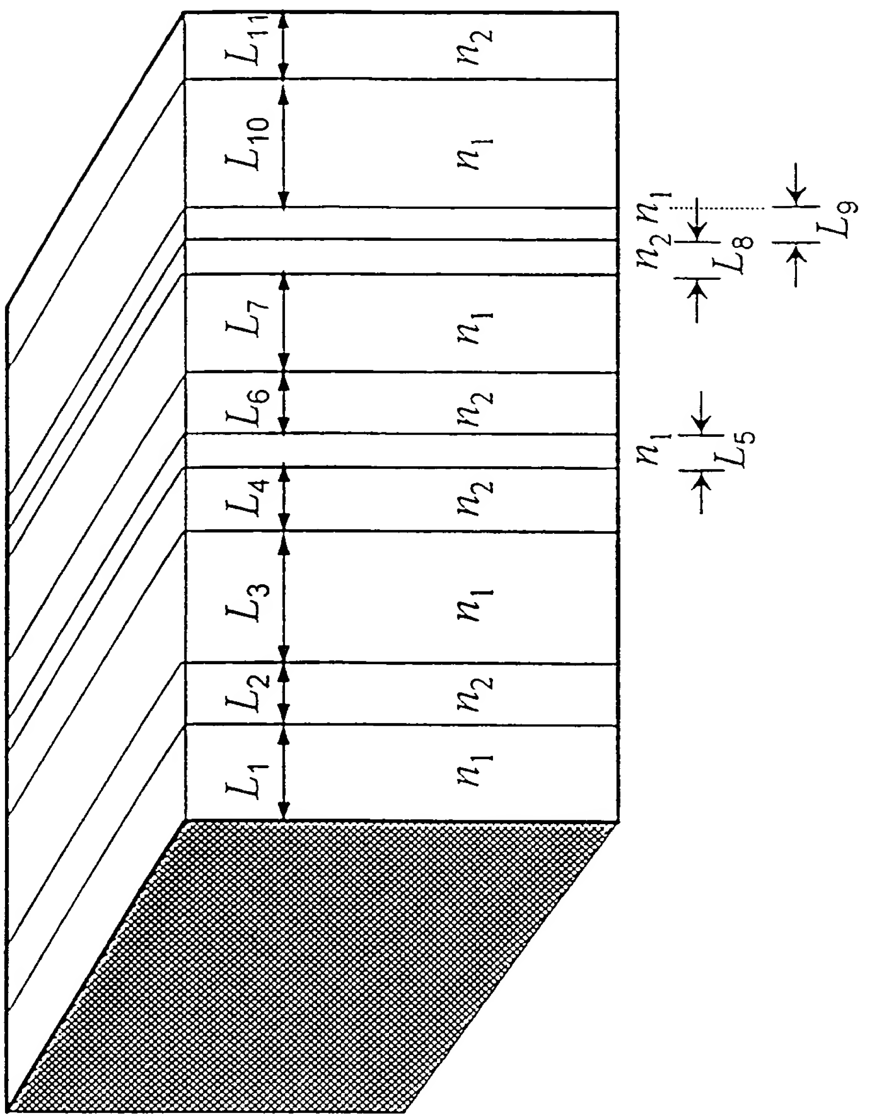


Fig. 10(a)

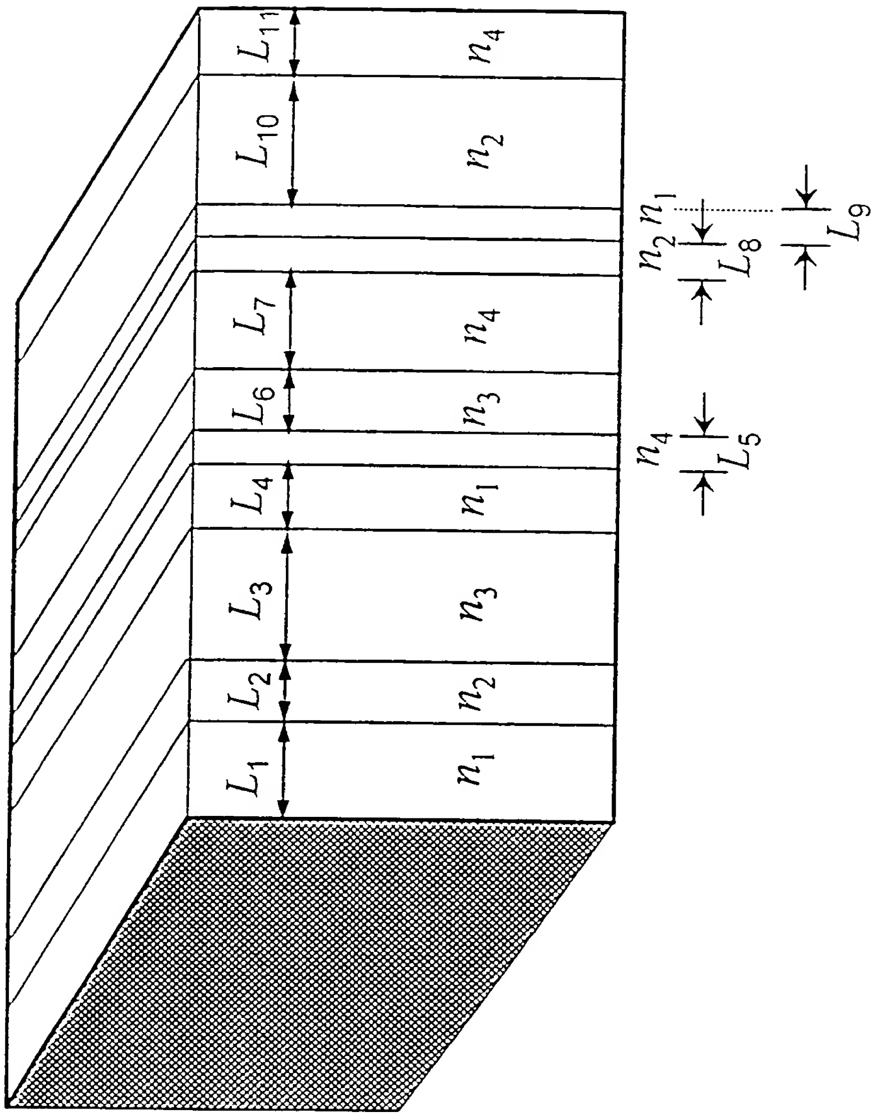


Fig. 10(b)

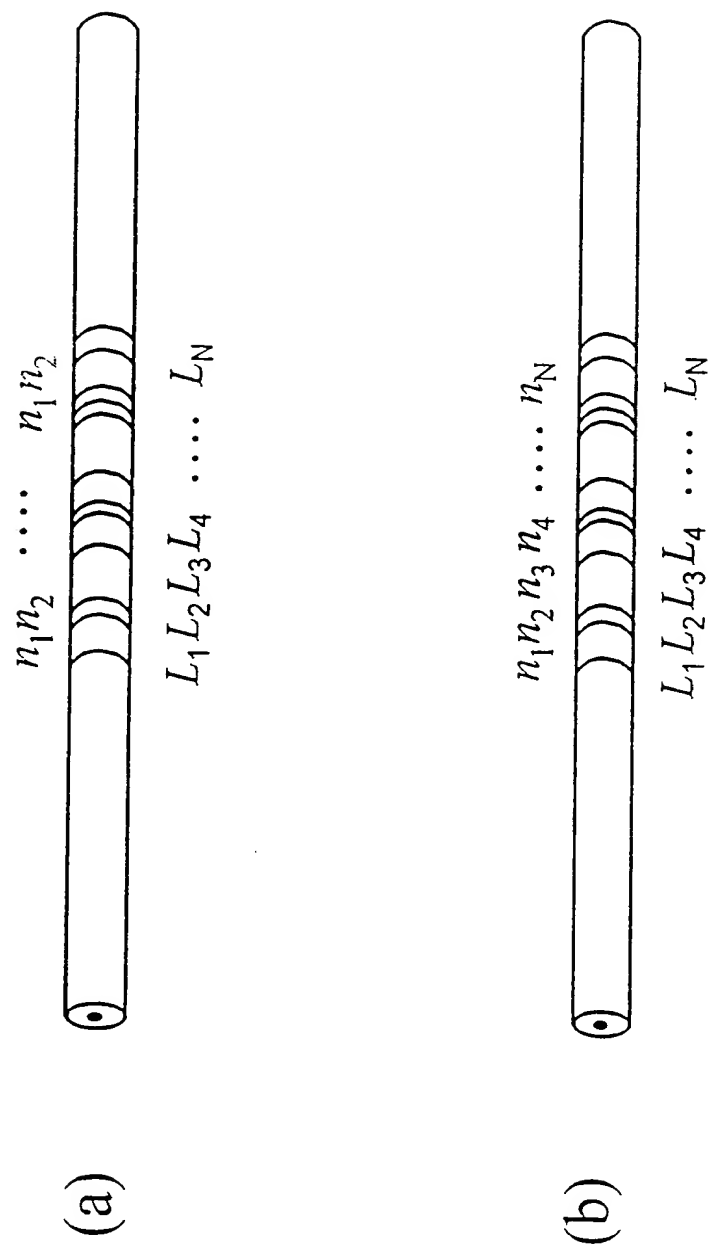


Fig. 11

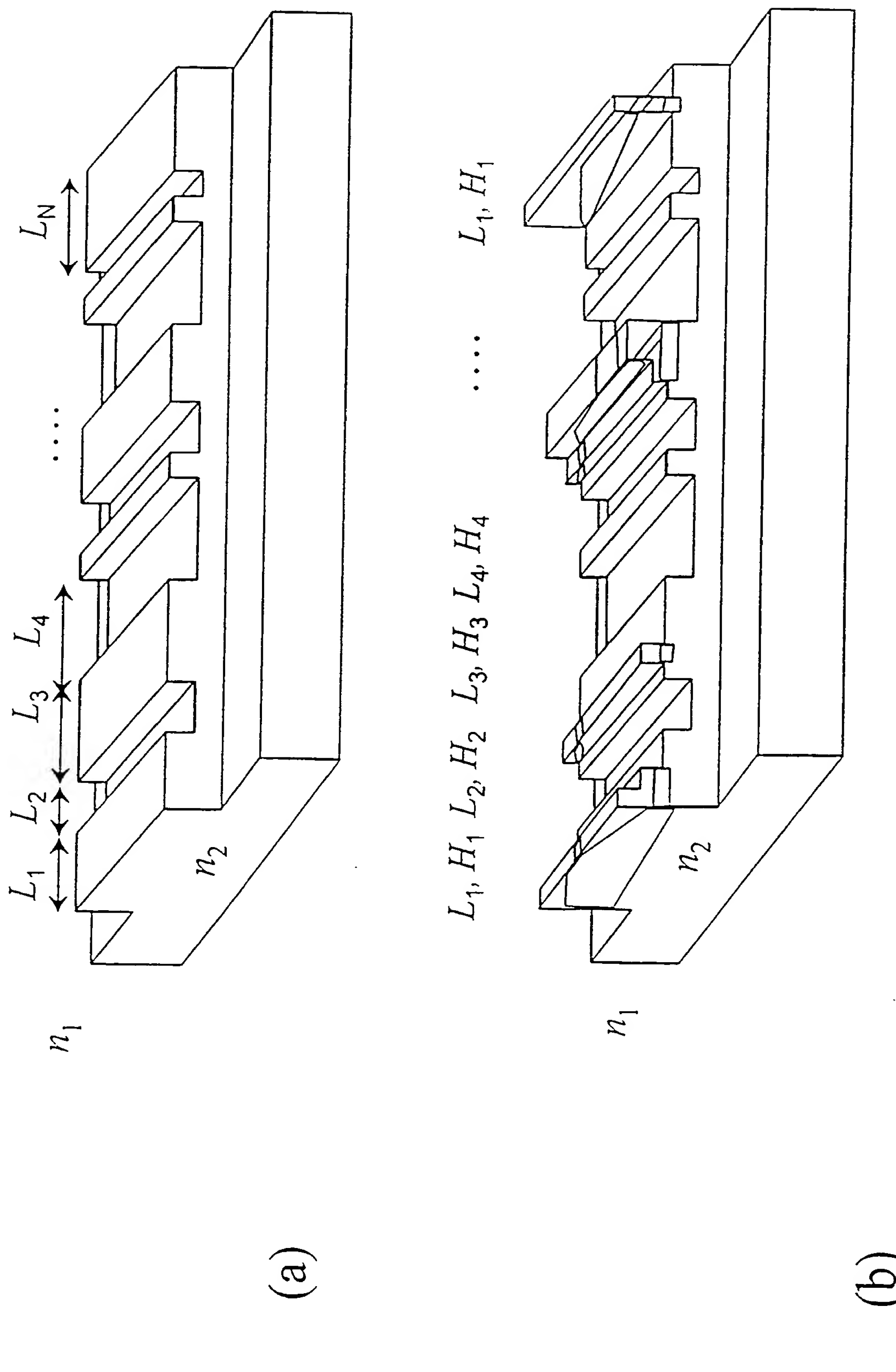
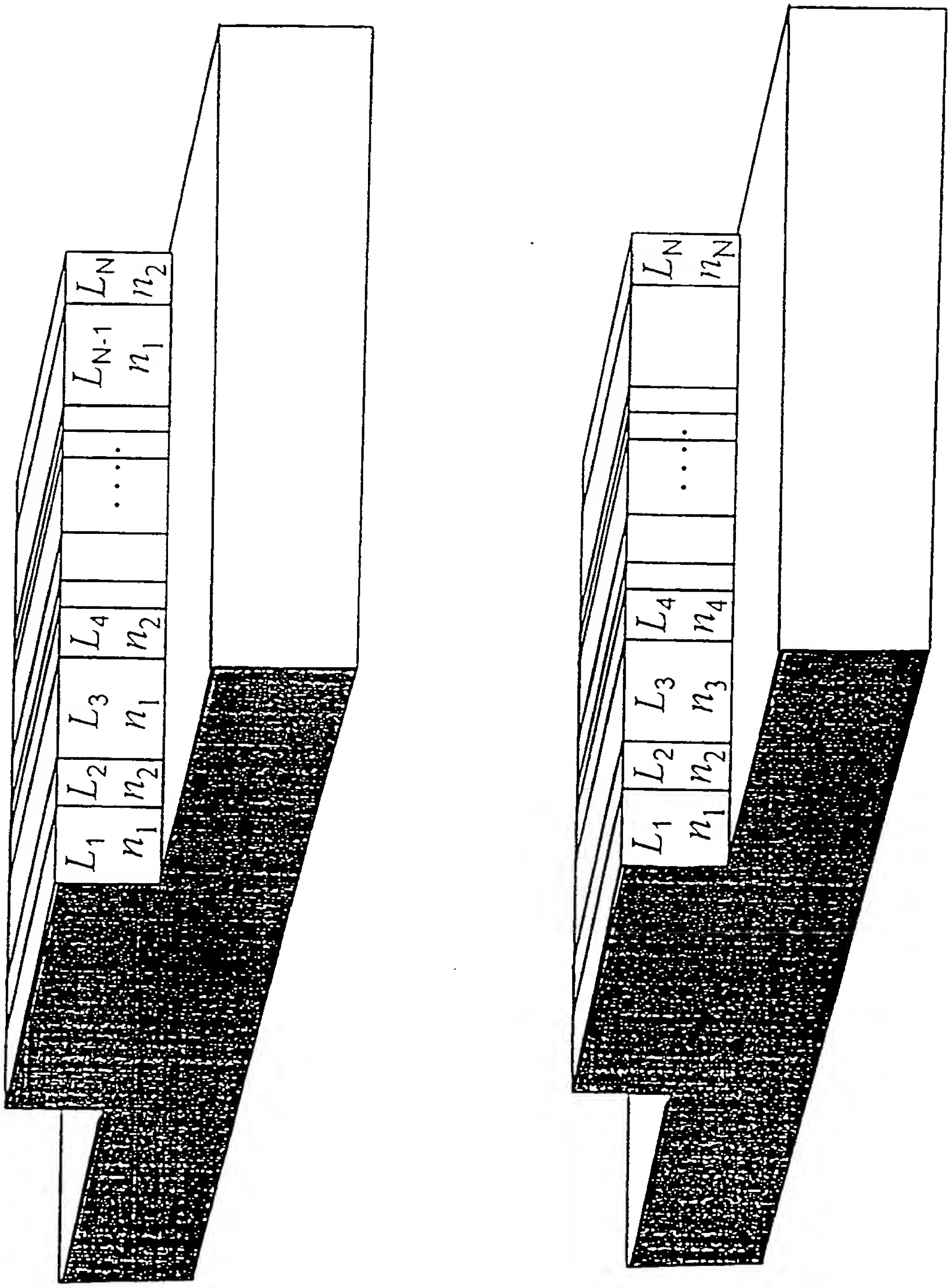


Fig. 12



(a)

(b)

Fig. 13

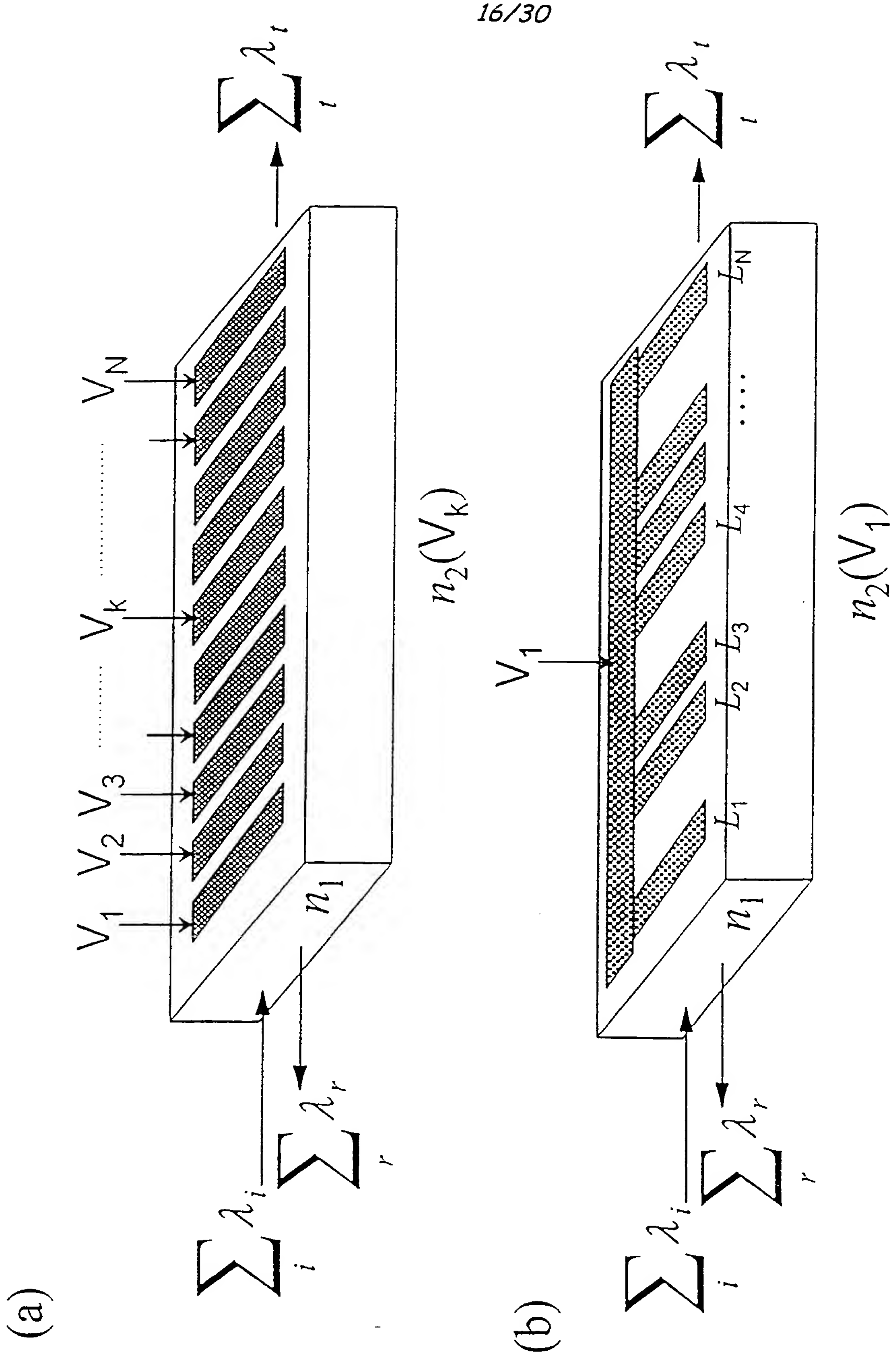

(a)
$\sum_i \lambda_i$
$\sum_r \lambda_r$
$\sum_t \lambda_t$
V_1
V_2
V_3
V_K
V_N
n_1
$n_2(V_K)$
(b)
$\sum_i \lambda_i$
$\sum_r \lambda_r$
$\sum_t \lambda_t$
V_1
L_1
L_2
L_3
L_4
L_N
n_1
$n_2(V_1)$

Fig. 14

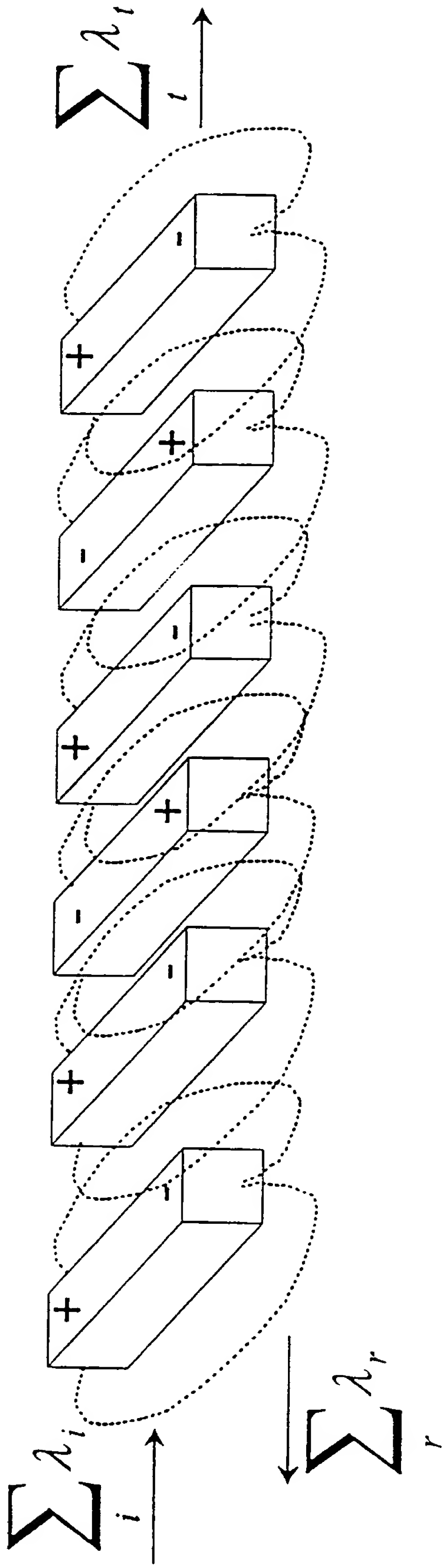


Fig. 15

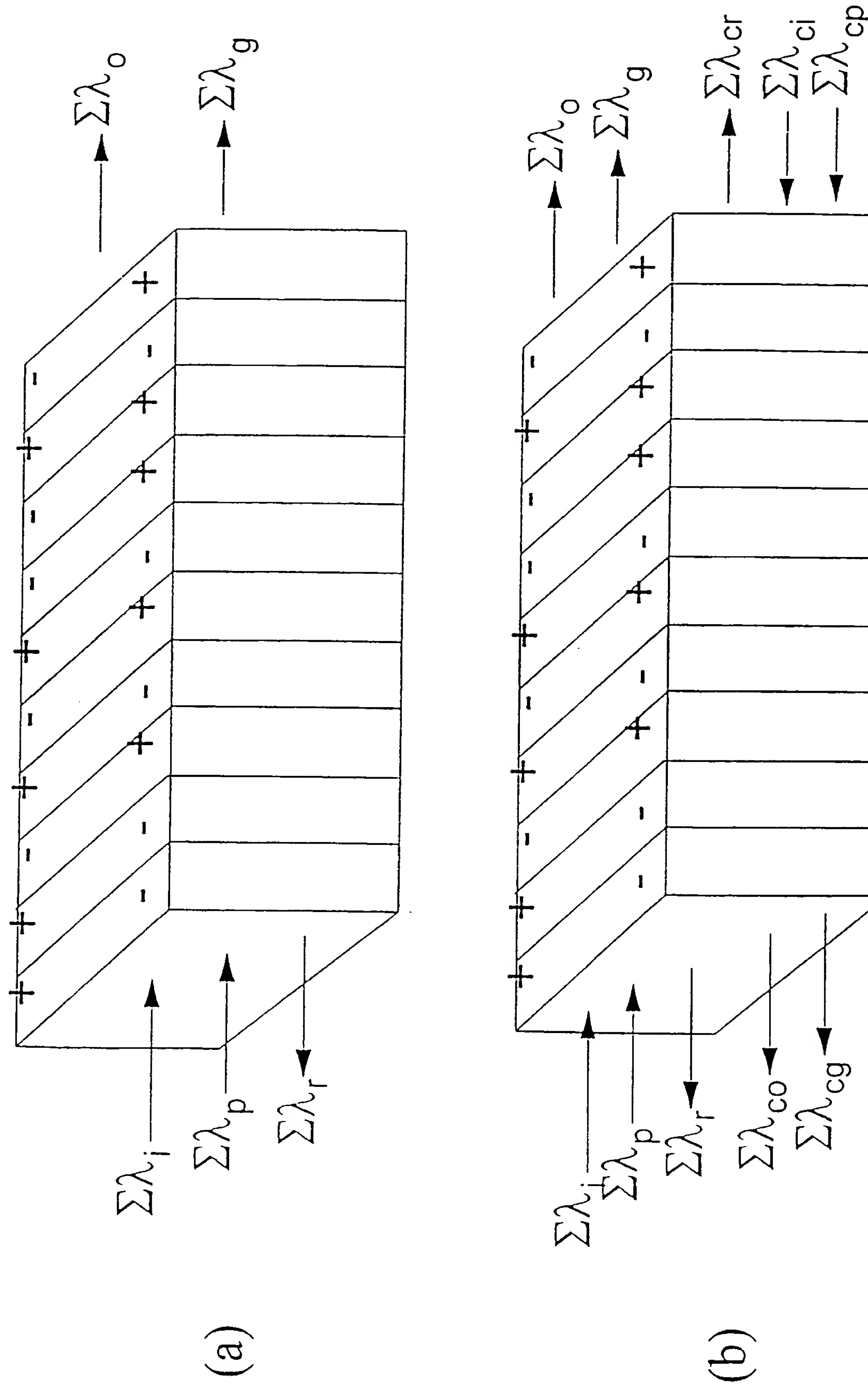

(a)
Σλi
Σλp
Σλr
Σλo
Σλg
(b)
Σλi
Σλp
Σλr
Σλco
Σλcg
Σλo
Σλg
Σλcr
Σλci
Σλcp

Fig. 16

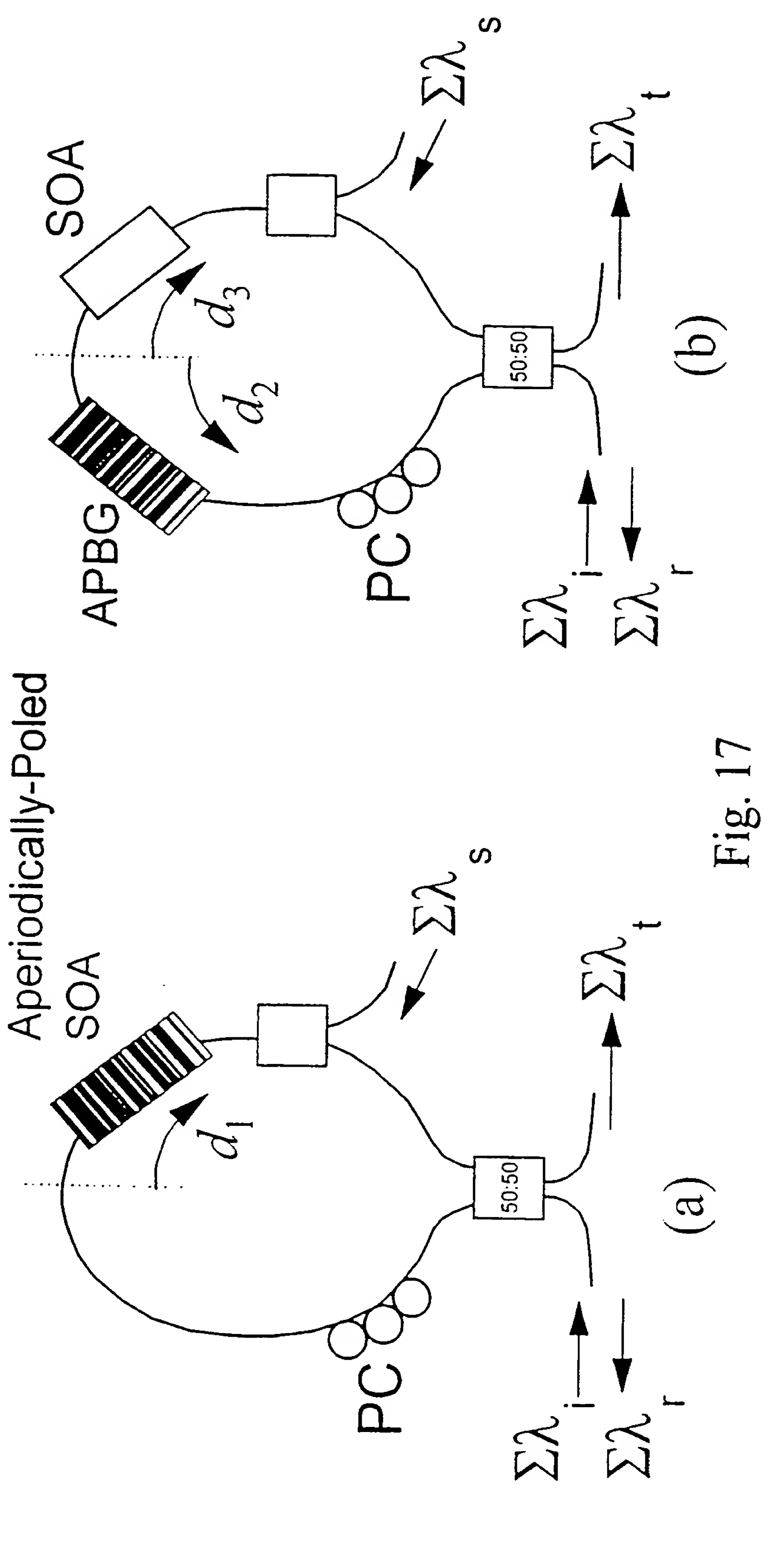

SOA
APBG
PC
50:50
d_3
d_2
$\Sigma\lambda_s$
$\Sigma\lambda_t$
$\Sigma\lambda_i$
$\Sigma\lambda_r$
(b)
Aperiodically-Poled
SOA
PC
50:50
d_1
$\Sigma\lambda_s$
$\Sigma\lambda_t$
$\Sigma\lambda_i$
$\Sigma\lambda_r$
(a)

Fig. 17

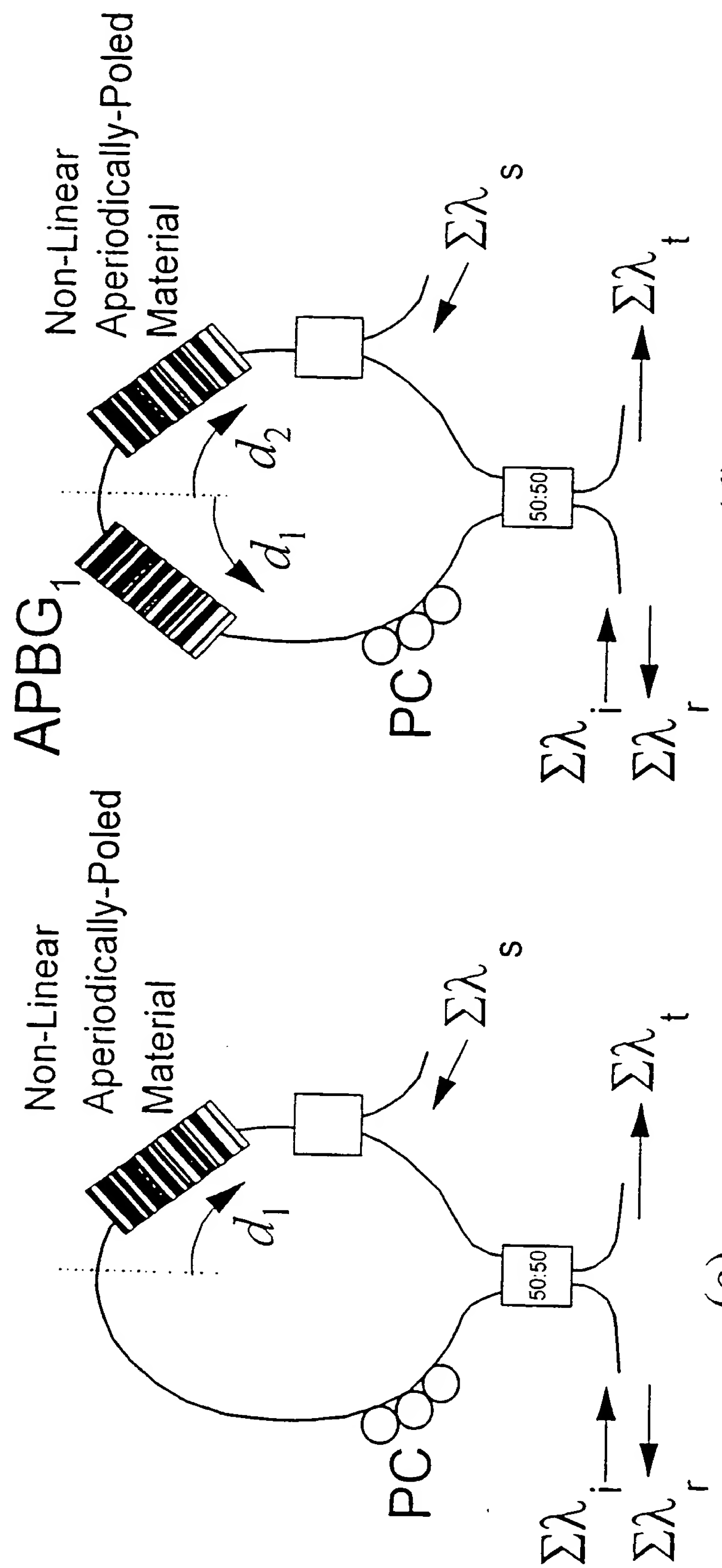

Non-Linear
Aperiodically-Poled
Material
APBG1
PC
d1
d2
50:50
Σλs
Σλt
Σλi
Σλr
(d)
Non-Linear
Aperiodically-Poled
Material
PC
d1
50:50
Σλs
Σλt
Σλi
Σλr
(c)

Fig. 17

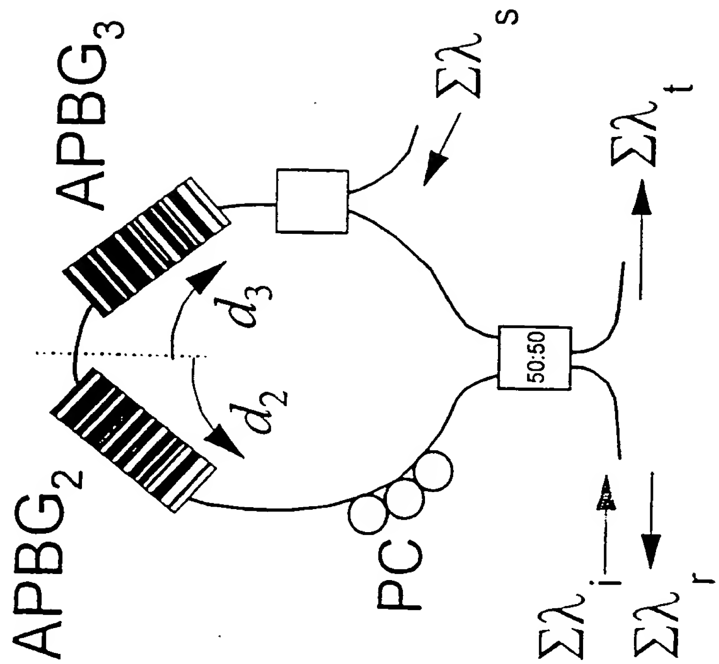

APBG$_2$
APBG$_3$
d_2
d_3
PC
50:50
$\Sigma\lambda_s$
$\Sigma\lambda_t$
$\Sigma\lambda_i$
$\Sigma\lambda_r$

Fig. 17(e)

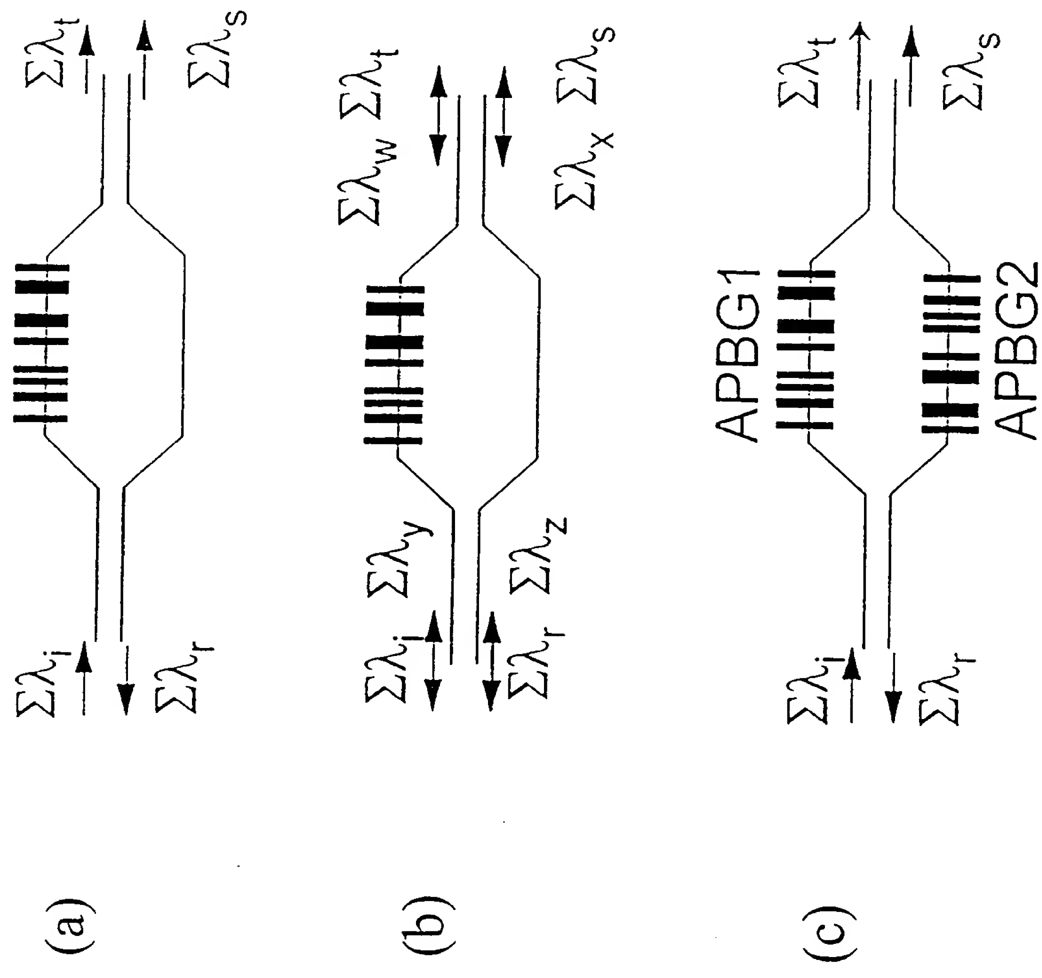


Fig.18

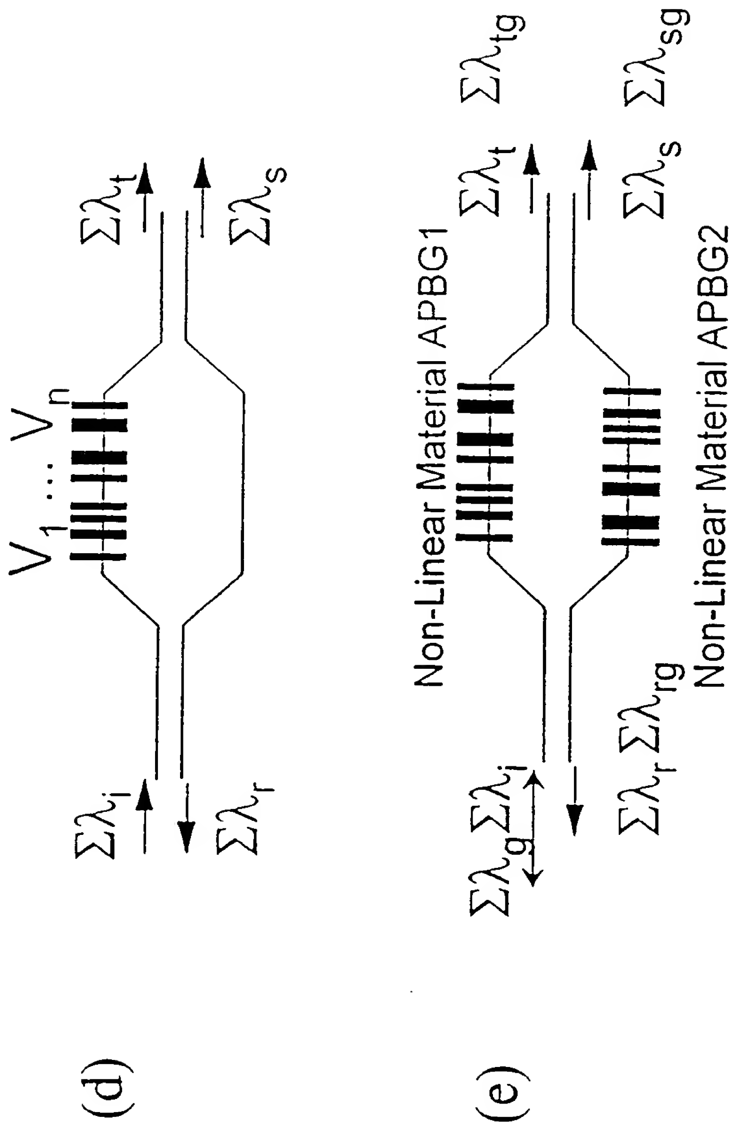

(d)
$V_1 \ldots V_n$
$\Sigma\lambda_i$
$\Sigma\lambda_r$
$\Sigma\lambda_t$
$\Sigma\lambda_s$
(e)
Non-Linear Material APBG1
Non-Linear Material APBG2
$\Sigma\lambda_g \Sigma\lambda_i$
$\Sigma\lambda_r \Sigma\lambda_{rg}$
$\Sigma\lambda_t$ $\Sigma\lambda_{tg}$
$\Sigma\lambda_s$ $\Sigma\lambda_{sg}$

Fig.18

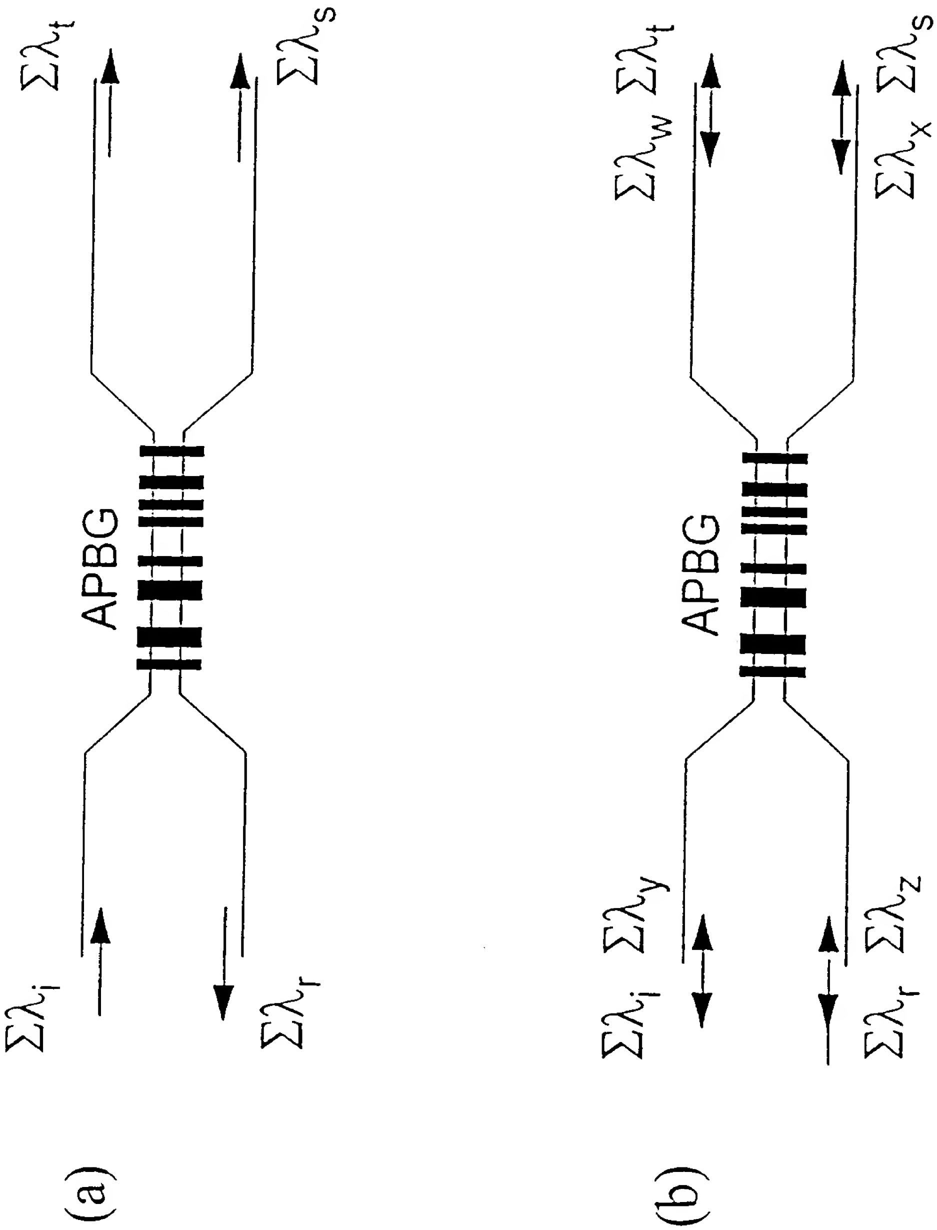

(a)
(b)
APBG
APBG
$\Sigma\lambda_i$
$\Sigma\lambda_r$
$\Sigma\lambda_t$
$\Sigma\lambda_s$
$\Sigma\lambda_y$
$\Sigma\lambda_z$
$\Sigma\lambda_w$
$\Sigma\lambda_x$

Fig. 19

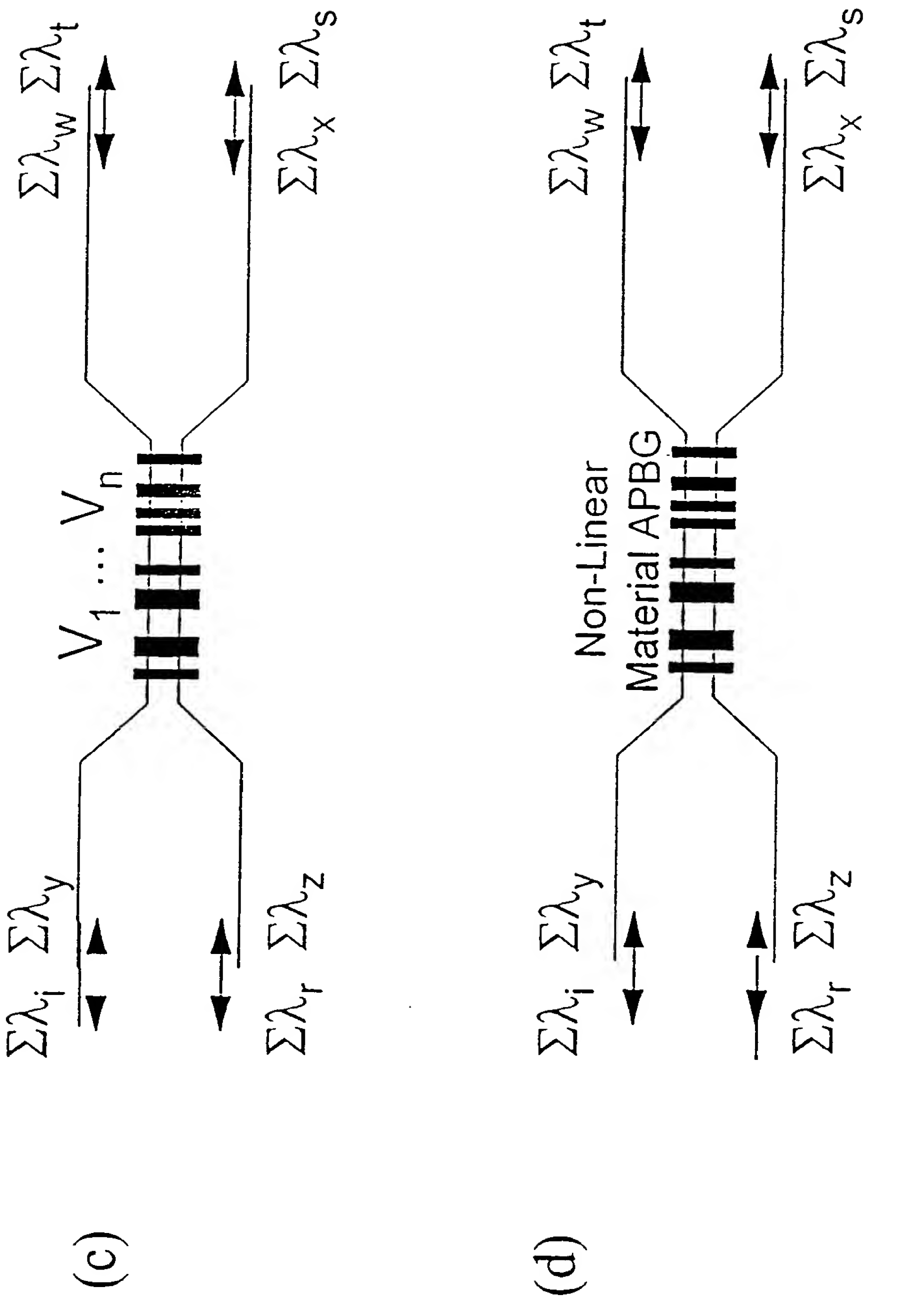

(c)
$\Sigma\lambda_w$ $\Sigma\lambda_t$
$\Sigma\lambda_x$ $\Sigma\lambda_s$
$V_1 \ldots V_n$
$\Sigma\lambda_i$ $\Sigma\lambda_y$
$\Sigma\lambda_r$ $\Sigma\lambda_z$
(d)
$\Sigma\lambda_w$ $\Sigma\lambda_t$
$\Sigma\lambda_x$ $\Sigma\lambda_s$
Non-Linear
Material APBG
$\Sigma\lambda_i$ $\Sigma\lambda_y$
$\Sigma\lambda_r$ $\Sigma\lambda_z$

Fig. 19

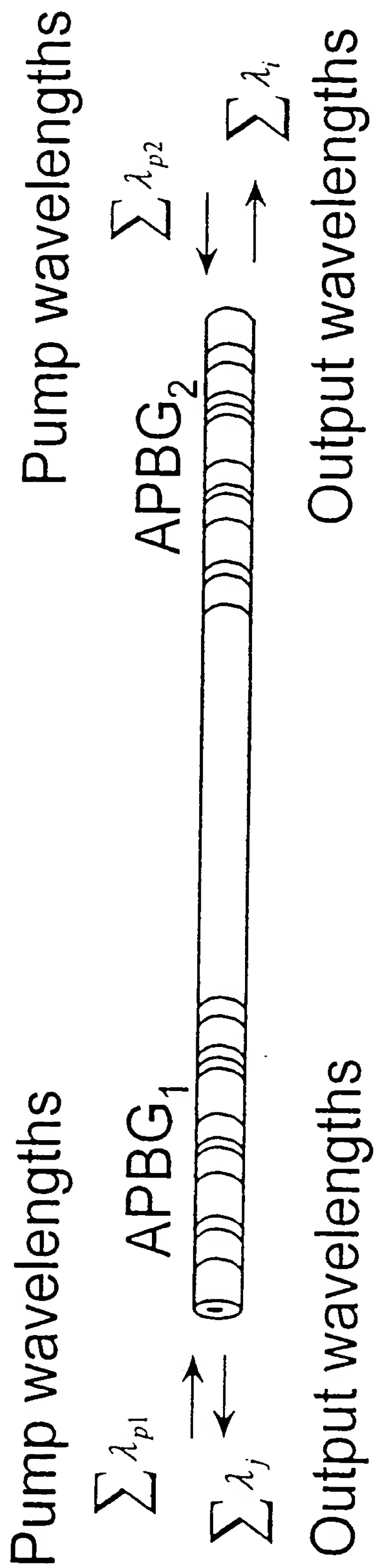

Pump wavelengths
$\sum \lambda_{p2}$
APBG$_2$
$\sum \lambda_i$
Output wavelengths
Pump wavelengths
$\sum \lambda_{p1}$
APBG$_1$
$\sum \lambda_j$
Output wavelengths

Fig. 20

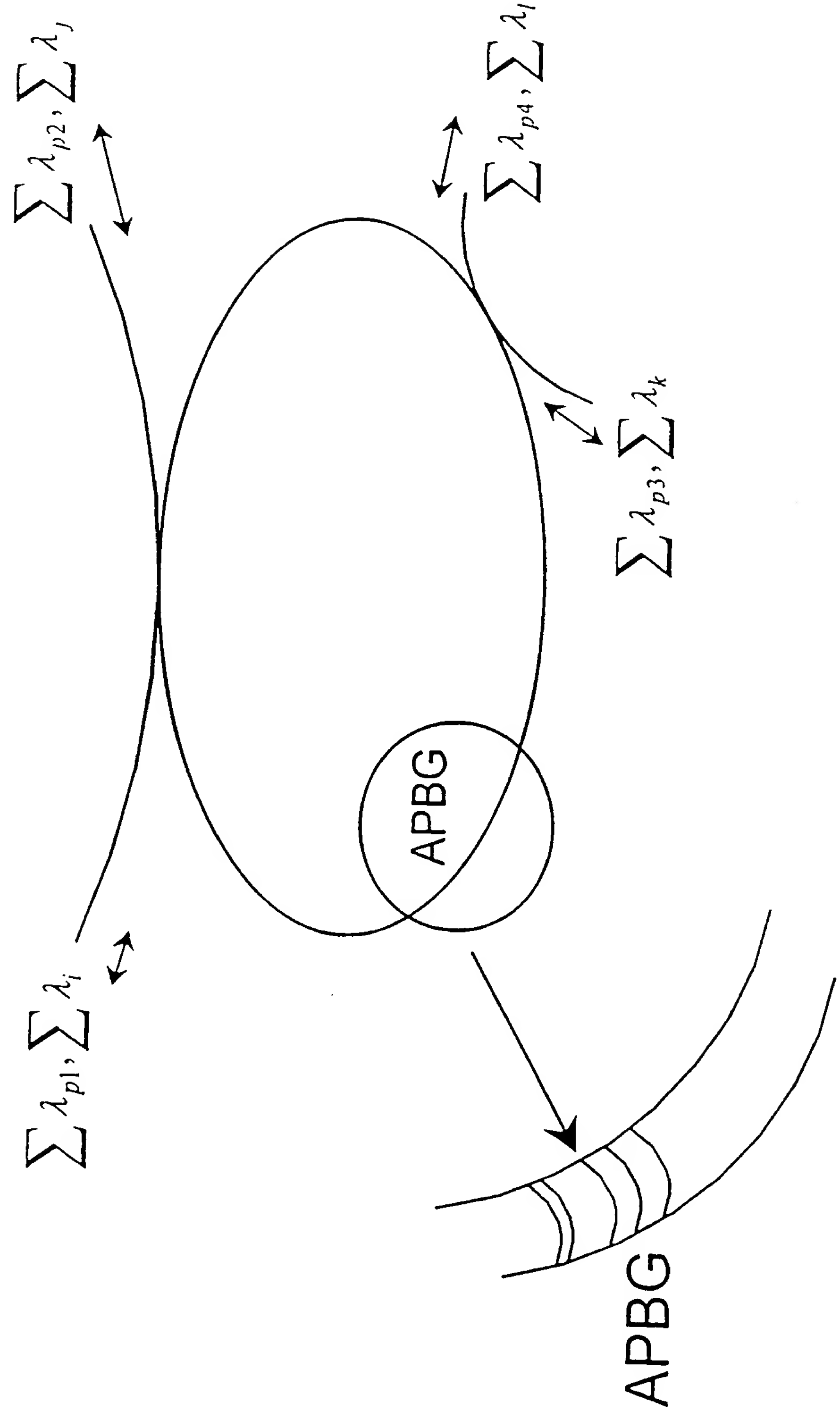

$\sum \lambda_{p2}, \sum \lambda_j$
$\sum \lambda_{p4}, \sum \lambda_l$
$\sum \lambda_{p3}, \sum \lambda_k$
$\sum \lambda_{p1}, \sum \lambda_i$
APBG
APBG

Fig. 21

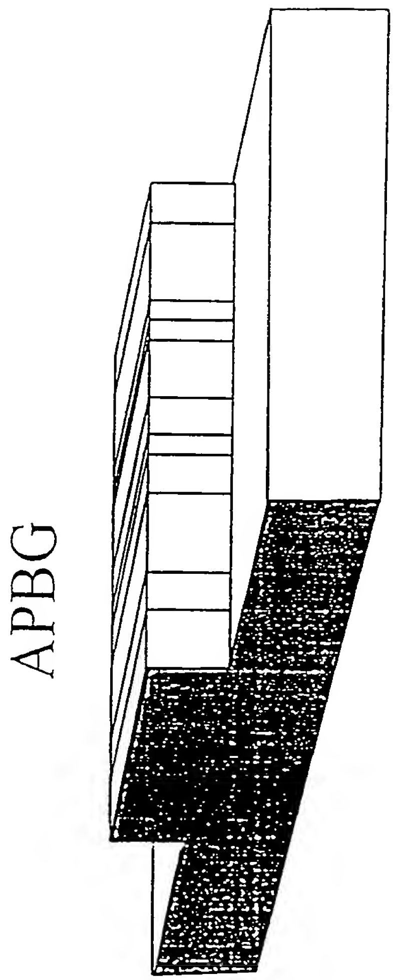


Fig. 22

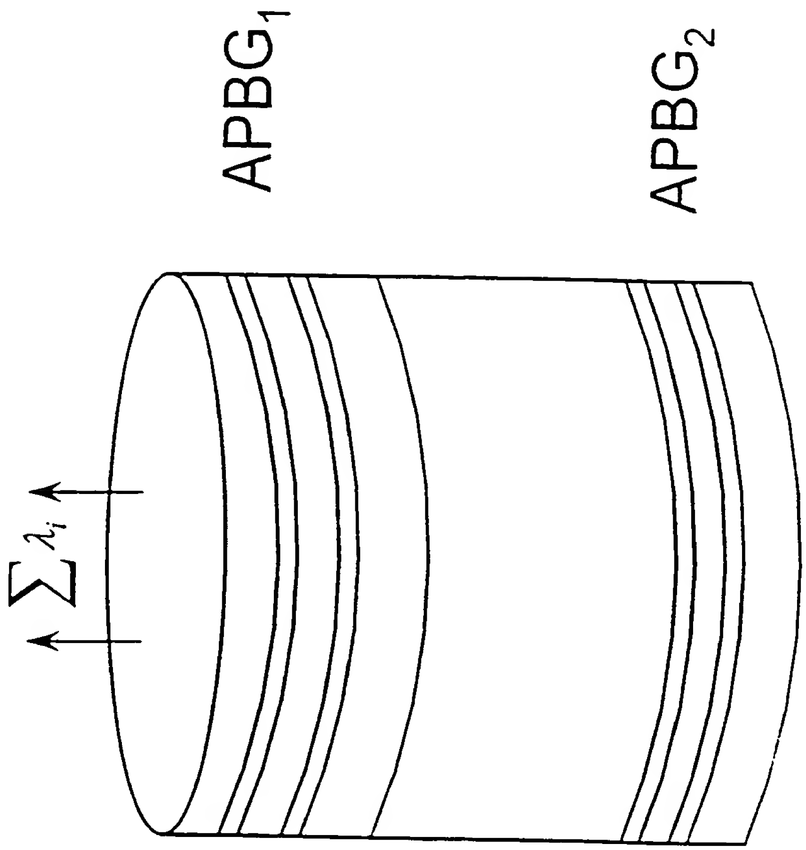


Fig. 23

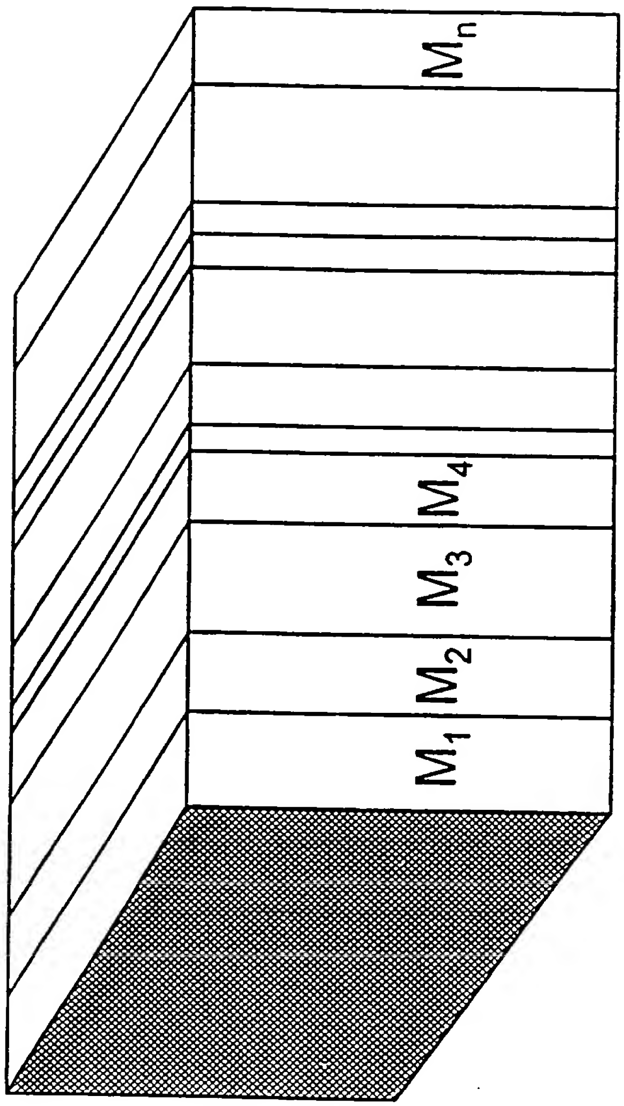


Fig. 24